British Upper Jurassic Stratigraphy (Oxfordian to Kimmeridgian)

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Chapter 2

Upper Jurassic stratigraphy from Dorset to Oxford

INTRODUCTION

J.K. Wright

The region covered in this chapter extends from the English south coast, between Weymouth and Chapman's Pool, east of Kimmeridge, northwards through north Dorset and Wiltshire to Wootton Bassett, and then north-eastwards through Oxfordshire to the M40 motorway east of Oxford (Figure 2.1). Three main units of strata are represented: the Weymouth Member of the Oxford Clay Formation and the Corallian Group, both of Oxfordian age, and the Kimmeridge Clay Formation, of Kimmeridgian age (see Figure 2.2). The Corallian Group comprises a series of shallow-water limestones, sandstones and ironstones, with subsidiary clays, and separates the two predominantly clay formations.

Sedimentation in the south of the region took place in a series of basins and troughs separated by 'highs' (Figure 2.1), with maximum thicknesses of Oxfordian strata frequently in excess of 140 m, and minimum thicknesses as low as 90 m. In the north, on the East Midlands Shelf between Swindon and Oxford (Figure 2.1), thicknesses of Oxfordian strata of between 70 and 90 m are common. In between, a large platform area associated with the Mendip High, stretching from Longleat to Wootton Bassett in Wiltshire, subsided more slowly, and the thickness of Oxfordian strata rarely exceeds 50 m. Though in general the Kimmeridge Clay covers the underlying three-dimensional patchwork quilt of sandstones, limestones and clays with a uniform blanket of clay, there is a marked reduction in its thickness northwards, and also incursions of sandy and iron-rich sediments near basin margins.

One of the principal reasons for the variations in thickness is that sedimentation in all areas during the Oxfordian and Kimmeridgian was affected by the operation of reactivated syndepositional faults (De Wet, 1987; Scotchman, 1991a; Bristow *et al.*, 1995; Newell, 2000). Within the Corallian Group in north Dorset, Bristow *et al.* (1995) have demonstrated marked effects of faulting on sedimentation. The consequences of the faulting were (a) to allow thicker sedimentation in hanging wall areas, and (b) by uplift of the footwall, to cause the erosion in the vicinity of the footwall of previously deposited units. Thus, for instance, in the Sturminster district of north Dorset, situated in the horst area known as the Cranbourne–Fordingbridge High, the thickness of Corallian strata is only on average 44 m. Syndepositional faults are situated both to the north and south (Figure 2.3), and so the thickness increases suddenly to 80 m in the Winterbourne Kingston Trough in the south and to 70 m in the Mere Basin in the north (Figure 2.3). The Highworth area north of Swindon was similarly affected, though the details have yet to be worked out. The effect on the ground is that limestone and clay members are often of only local extent, and may pass laterally into sandstones close to the basin margin. This is particularly the case on the Longleat–Wootton Bassett Platform and on the southern part of the East Midlands Shelf to the north-east. Less complicated variations in facies and thicknesses during the Kimmeridgian Age were also caused by differential fault movements (Scotchman, 1991a; Newell, 2000).

In the Early Oxfordian, sedimentation was dominated by the moderately deep-water Oxford Clay facies, which spread across the area with little variation in sediment type, except for an incursion of silts on the Dorset coast. In the late Early Oxfordian, shallow-water sedimentation, represented by the Corallian Group, began abruptly. The principal subdivisions of the Corallian Group are shown in Figure 2.2. Thus in the southern half of the area, Oxford Clay is overlain by sands (Nothe Grit Formation, Hazelbury Bryan Formation, Lower Calcareous Grit), whereas south and east of Oxford, this interval is represented by the silty muds and fine sands of the lower West Walton Formation and the Temple Cowley and Arngrove Spiculite members.

Middle Oxfordian sediments of the Dorset basins consist predominantly of limestone–clay alternations (Redcliff, Osmington, Stour formations), and these pass northwards into predominantly sandstone–limestone sequences (Kingston and Stanford formations) in Wiltshire and Oxfordshire. In the shallow-water area around Oxford there was a lateral transition into the medium- to coarse-grained sands of the Beckley Sand Member, with its renowned highly fossiliferous shell beds. There is a diminution in quartz sand content upwards, and at the close of the Mid Oxfordian, coralliferous micritic limestone (Coral Rag Member, with its associated bioclastic facies (Wheatley Limestone)) was being laid down over much of the area. Locally, these lime-

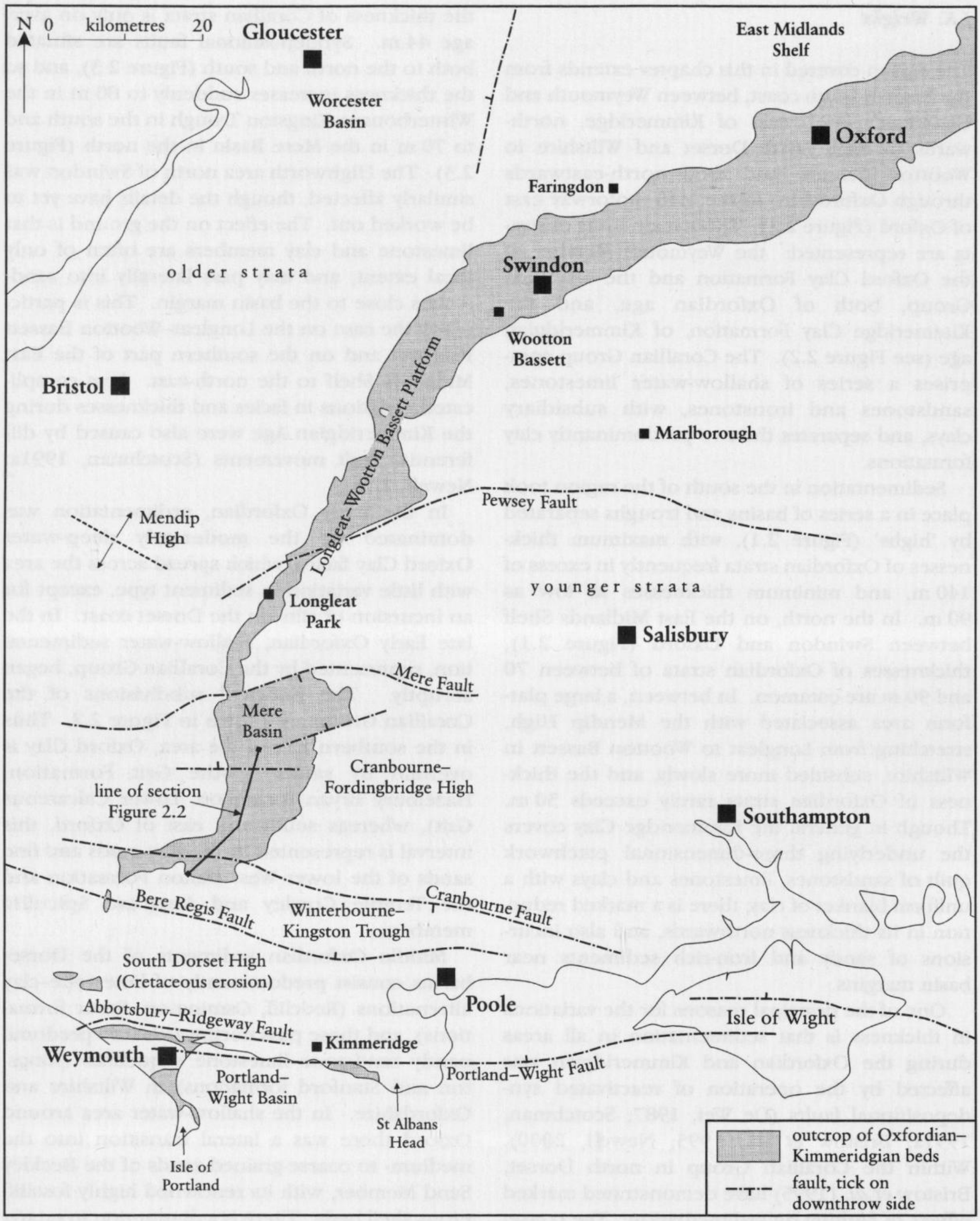


Figure 2.1 **Map of southern England showing the outcrop of the Oxfordian–Kimmeridgian beds, and the principal structural and palaeogeographical features (based on Scotchman, 1991a, fig. 1; Bristow *et al.*, 1995, fig. 6 and Newell, 2000, fig. 6).**

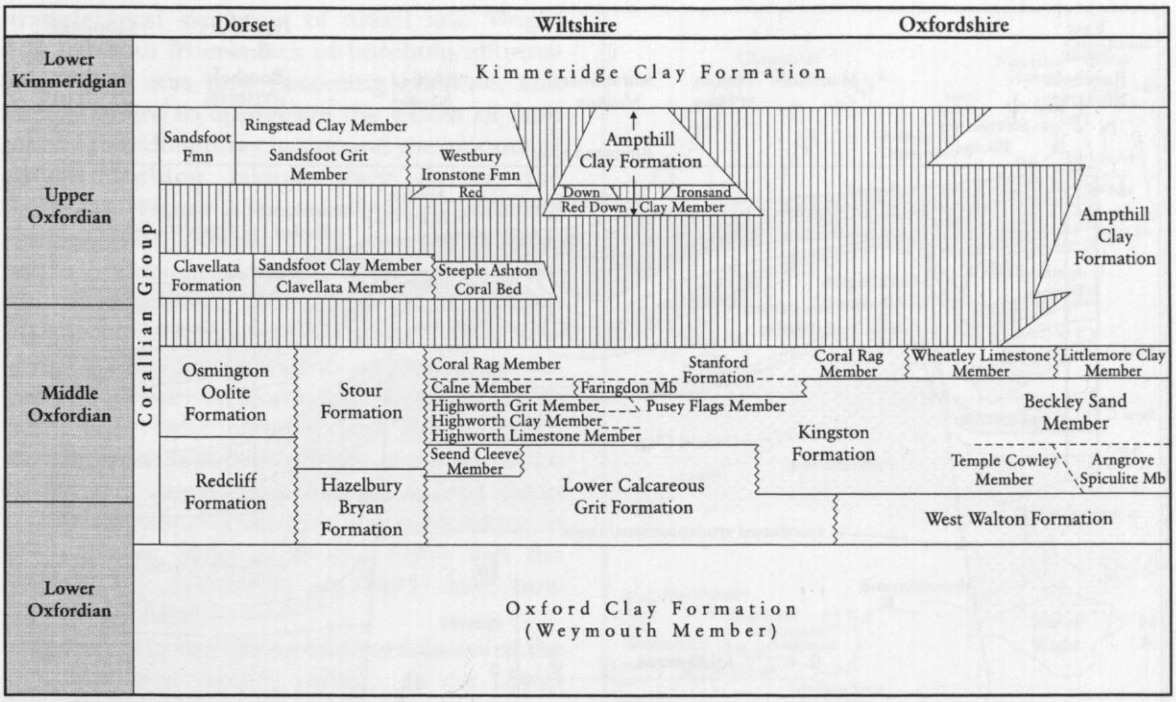


Figure 2.2 Correlation of Oxfordian strata in Dorset, Wiltshire and Oxfordshire.

stones pass into clay facies (Littlemore Clay). North-east of Oxford, the shallow-water limestones and sandstones both pass laterally into the silts of the upper West Walton Formation. The silty nature of Middle Oxfordian sedimentation, even in areas nominally of deeper water (East Midlands), is a clear indicator of marine regression, a widespread Early to Mid Oxfordian event.

The Upper Oxfordian sediments are very variable, being predominantly sand–clay (Dorset), ironstone (south Wiltshire) or argillaceous (Swindon). Around Oxford, they are frequently thin or absent, but east of Oxford they occur completely in clay facies (Ampthill Clay) (see Chapter 3). In general, there was a return to deeper-water clay sedimentation, but the Late Oxfordian was a period of tectonic instability in southern England, with frequent uplifts, and localized shallow-water deposits and hiatuses are common.

Early Kimmeridgian times saw continued regional subsidence/sea-level rise, which led to clay facies rocks being deposited over much of the area, though passing locally into sandy ironstone facies (Abbotsbury Ironstone) in the west. Argillaceous conditions continued into the Late Kimmeridgian in south Dorset, leading to a total accumulation of more than 500 m of Kimmeridge Clay in the Kimmeridge area. This thickness is reduced to 250 m only 20 km west, near Weymouth. Northwards, Cretaceous erosion means that the original full thickness of the Kimmeridge Clay is unknown right up to the Wiltshire border, where 265–300 m is reported at Mere. At Westbury, the thickness is reduced to 120 m, increasing to 150 m at Calne, but only 100 m at Swindon. Around Oxford, the thickness is only about 50 m, reducing to 37 m east of Oxford at the M40 (Horton *et al.*, 1995). The total thickness of Kimmeridgian strata around Oxford is thus only a tenth of that reached in the Wessex Basin at Kimmeridge. In the Highworth area and around Oxford, the Upper Kimmeridgian is largely represented by sands containing huge doggers.

The number of workers on the Oxfordian–Kimmeridgian of the area is too many to list individually in this introduction. Only those who have contributed on a broad, regional scale are mentioned below, and reference will be made to more detailed work in the individual site descriptions. The basis for our understanding of the Oxfordian–Kimmeridgian of the area

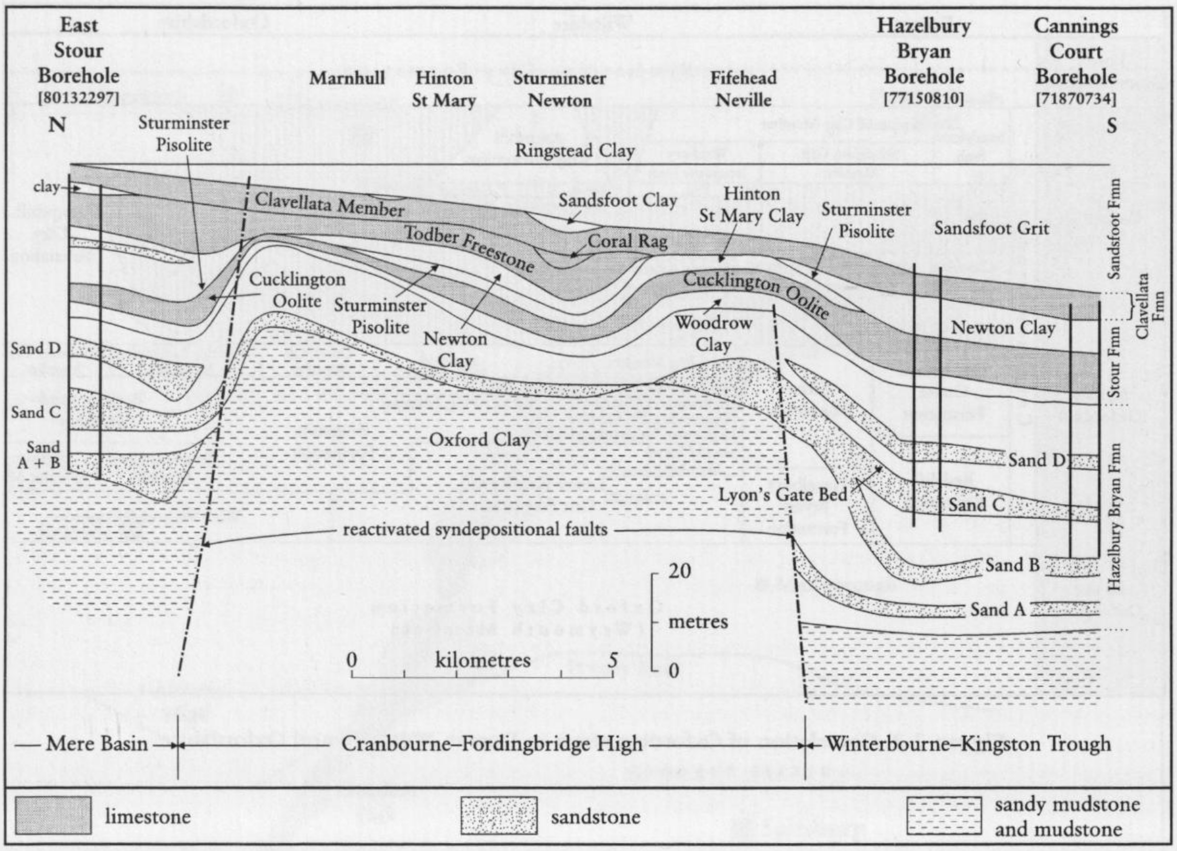


Figure 2.3 Cross-section of north Dorset, showing the effect of syndepositional faulting on the thicknesses of the Corallian beds (after Bristow *et al.*, 1995, fig. 38).

was set by the monumental works of Blake (1875) and Blake and Hudleston (1877). These works are repeatedly referred to today, describing as they do many sections no longer visible. During the 1860s and 1870s, and again in the 1920s, the area was mapped by the Geological Survey. Though much of this was done on a six-inch scale, some areas of Corallian outcrop, particularly in the Shaftesbury Sheet area, were only available until recently in the original one-inch scale mapping. The results of the 19th-century mapping were summarized by Woodward (1895).

During the 1930s, it became apparent to W.J. Arkell that a proper understanding, particularly of the Corallian Group, would only be achieved by detailed mapping on a six-inch scale, and Arkell set himself the task of mapping those areas that included Corallian beds from east of Oxford southwards to north Dorset. The results of this work were published in a series of papers (Arkell, 1939a, 1941b, c, 1942, 1944a, b, 1951). The only areas he did not complete were north Dorset and south Wiltshire. The results of mapping in north Dorset were published by Wright (1981). Arkell (1936a, 1947a) also worked extensively on the Dorset coast. Wright (1980, 1986a, b) revised Arkell's work and formalized the lithostratigraphical nomenclature in line with modern practice.

From the 1960s onwards, the area has been the focus of a considerable amount of work on sedimentology, palaeoenvironmental analysis, and aspects of cyclic sedimentation (Wilson, 1968a, b; Brookfield, 1973a, b, 1978; Talbot, 1973a, 1974; Sun, 1989; Newell, 2000). The realization that Oxfordian sandy beds in Dorset had at one time been oil reservoir rocks, with the discovery nearby of the Wytch Farm Oilfield, led to considerable attention being paid to these rocks by oil companies.

During the 1990s, it was realized that the stratigraphical syntheses of Arkell and Wright suffered both from a lack of borehole information, which was now becoming available, and from a failure to appreciate the extent of fault control of sedimentary basins and the amount of growth faulting taking place during the Oxfordian (Figure 2.3). Arkell's 'axes' affecting sedimentation (Arkell, 1933, chapter 3) were only a preliminary attempt to assess the problem. In general, Arkell explained sudden changes in thickness by folding and crustal flexuring. Only where there was no alternative, i.e. the Peak Fault in north-east Yorkshire (Fox-Strangways, 1892; Rawson and Wright, 2000) were Jurassic fault movements accepted as the explanation for sudden changes in bed thickness. Substantial revision of the successions in north Dorset (Bristow *et al.*, 1995) and the Oxford area (Horton *et al.*, 1995) have now proved necessary.

Problems in the dating and correlation of the beds have been largely solved. In the Lower Oxfordian, ammonites, particularly cardioceratids, are often prolific, and the subdivisions of Arkell (1941a) have stood the test of time. For the Middle and Upper Oxfordian, the situation is not quite as straightforward. The occurrence of specific ammonite groups became dependent on facies during this period. The perisphinctids were largely confined to limestone and sandstone facies. The cardioceratids, though often accompanying the perisphinctids in these shallow-water facies, were often the only group present in clay facies. It has proved necessary in both the Middle and Upper Oxfordian to set up separate zonal and subzonal schemes for perisphinctids and for cardioceratids (see Figure 1.4). Precise correlation of the two schemes is still uncertain. For the sake of continuity, the cardioceratid zonal scheme is used throughout in this volume. Prolific perisphinctid faunas have been found in the Middle Oxfordian shell beds of the Oxford area, and in the Upper Oxfordian Clavellata Member and Osmington Mills Ironstone Member of south Dorset. Correlation of these faunas with cardioceratid faunas has proved possible at Dimmock's Cote Quarry (Middle Oxfordian), Leysthorpe Quarry (lower Upper Oxfordian) and Staffin (upper Upper Oxfordian) (see reports in this volume).

The zonation of the Kimmeridgian Stage is more straightforward. The excellence of exposure on the coast (Upper Kimmeridge Clay; Cox and Gallois, 1981) and at Westbury Cement

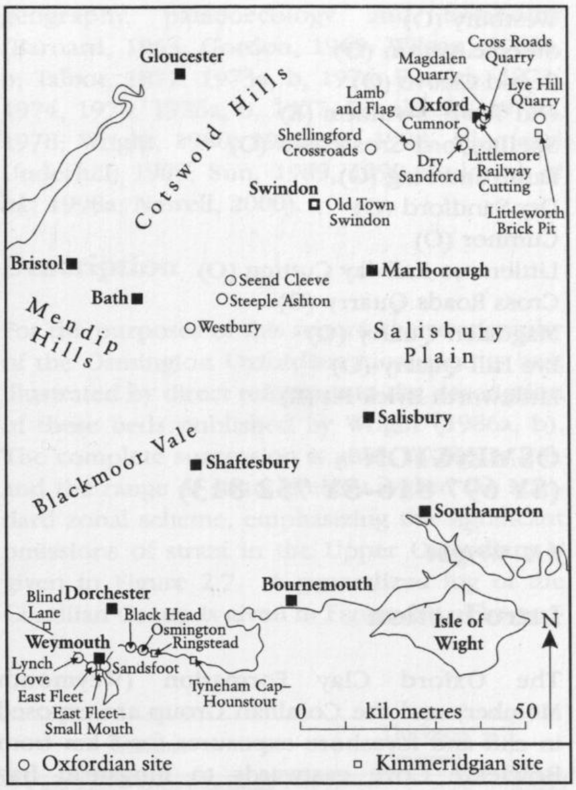


Figure 2.4 Locations of Oxfordian and Kimmeridgian GCR sites in southern England.

Works, Wiltshire (Lower Kimmeridge Clay; Birkelund *et al.*, 1983), combined with an abundant ammonite fauna in clay facies, means that the ammonite succession is well documented, although there are a few problems of detailed correlation because of homeomorphy in the Upper Kimmeridgian genus *Pectinatites*.

Details of the main lithologies and depositional environments are included in the site descriptions that follow. In the following list (arranged from south to north), (O) indicates that the site belongs to the Oxfordian GCR Block, and (K) the Kimmeridgian GCR Block. The site locations are shown in Figure 2.4.

Osmington (O)
Black Head (K)
Ringstead (K)
Sandsfoot (O)
East Fleet–Small Mouth (K)
East Fleet (O)
Lynch Cove (O)
Tyneham Cap–Hounstout (K)
Blind Lane (K)

Westbury (O)
Steeple Ashton (O)
Seend Cleeve (O)
Old Town, Swindon (K)
Shellingford Crossroads (O)
Lamb and Flag (O)
Dry Sandford (O)
Cumnor (O)
Littlemore Railway Cutting (O)
Cross Roads Quarry (O)
Magdalen Quarry (O)
Lye Hill Quarry (O)
Littleworth Brick Pit (K)

OSMINGTON (SY 697 816–SY 752 813)

J.K. Wright

Introduction

The Oxford Clay Formation (Weymouth Member) and the Corallian Group are exposed in cliff and foreshore exposures for 5 km from Bowleaze Cove eastwards to Ringstead Bay (Figure 2.5). These exposures are the standard for the Oxfordian Stage in southern Britain, and constitute a site of international importance. A near-complete Lower and Middle Oxfordian succession is available, and the Upper Oxfordian is well developed, though having substantial gaps in the succession owing to intraformational erosion. The section has both stratigraphical and historical interest; it includes the type localities for several stratigraphical units, and has produced the type and figured specimens of many fossil species.

The geological prominence of the Osmington exposures first became apparent in the early 19th century when the site was described by Adam Sedgwick (1826). Both Fitton (1827) and Buckland and De la Beche (1836) later provided brief accounts. The first full descriptions of the stratigraphy were those given by Blake and Hudleston (1877, pp. 262–72), Damon (1884, pp. 22, 29, 38–46, plus map) and Woodward (1895, pp. 82–8). Woodward's account was based largely on the work of Blake and Hudleston (1877), these latter authors providing the most complete descriptions of the site in the 19th century.

Buckman (1923–1925, pp. 63–5) described the succession at the site, introducing several new stratigraphical terms, and figuring ammon-

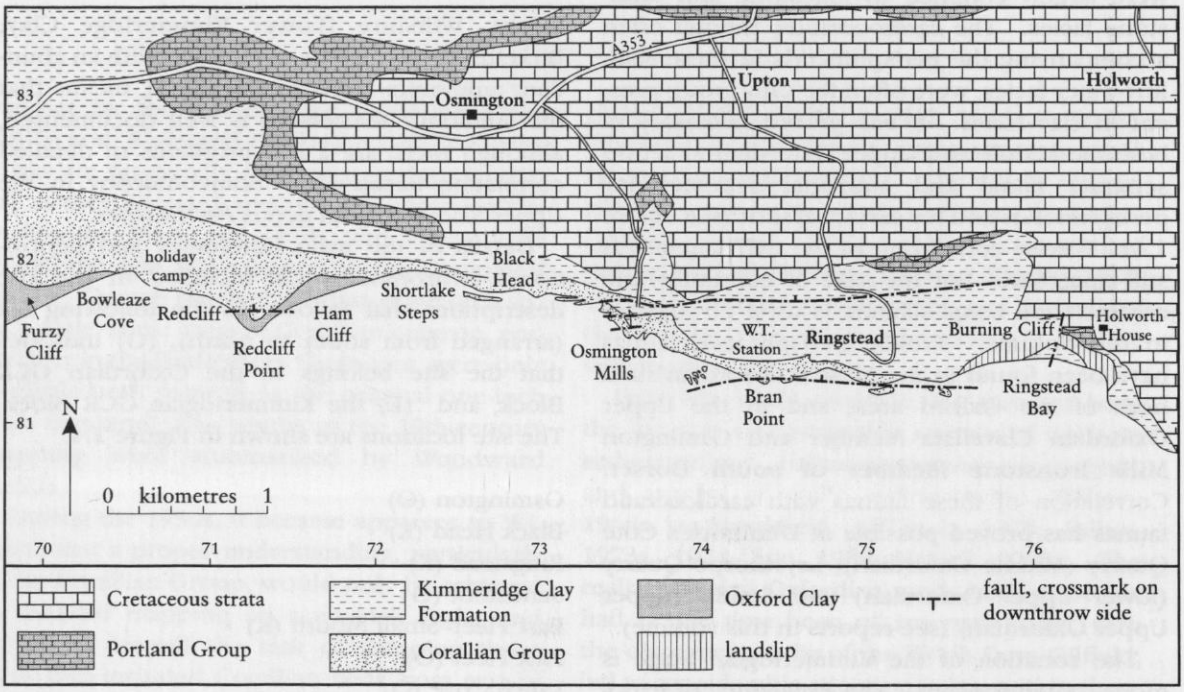


Figure 2.5 Sketch map of the solid geology of the Furzy Cliff–Ringstead Bay area (based on Cox and Gallois, 1981, fig. 5 and BGS Sheet 341/342 (West Fleet and Weymouth) 1976).

ites collected here. However, it was Arkell's classic studies of the rich bivalve and ammonite faunas (1929–1937, pp. 387–92 with distribution table and 1935–1948, pp. 66–7, 385–6 (lists of figured and cited specimens from the Dorset coast)) that best emphasize the key role played by this site in the studies of Oxfordian geology. Furthermore, Arkell's classic memoir on the geology of south Dorset (Arkell, 1947a), which describes the Osmington site in detail, is still in print some 60 years after it was written.

During the 1960s, 1970s and 1980s, important general descriptions of the Osmington section were published by Cope and Torrens (1969, pp. A43–6), House (1989) and MacFadyen (1970, pp. 110–14). Detailed, up-to-date reviews are given by Callomon and Cope (1995) and Coe (1995). The locality figured prominently in several specialist studies concerning Oxfordian stratigraphy, sedimentology, palaeogeography, palaeoecology and taxonomy (Barnard, 1953; Gordon, 1965; Wilson, 1968a, b; Talbot, 1971, 1973a, b, 1974; Fürsich, 1973, 1974, 1975, 1976a, b, 1977; Brookfield, 1973a, 1978; Wright, 1980, 1986a, b, 1998; Allen and Underhill, 1989; Sun, 1989, 1990; Goldring *et al.*, 1998a; Newell, 2000).

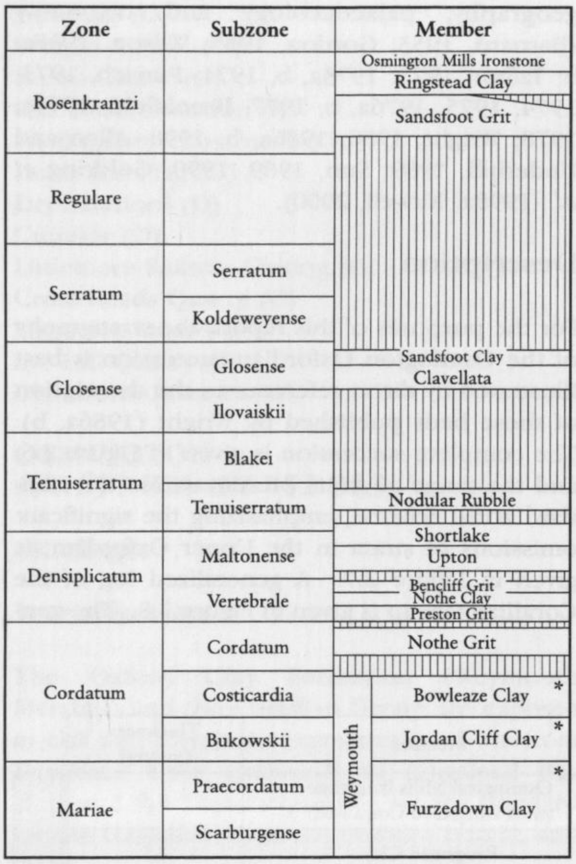
Description

For the purposes of this report, the stratigraphy of the Osmington Oxfordian succession is best illustrated by direct reference to the description of these beds published by Wright (1986a, b). The complete succession is given in Figure 2.6, and the range of strata present within the standard zonal scheme, emphasizing the significant omissions of strata in the Upper Oxfordian, is given in Figure 2.7. A generalized log of the Corallian Group is given in Figure 2.8. The gen-

Substage	Formation	Member		Thickness (metres)	
Upper Oxfordian	Sandsfoot	Osmington Mills Ironstone (with Ringstead Coral Bed)		0.5	Corallian Group
		Ringstead Clay		3.5	
		Sandsfoot Grit		7.35	
		Sandsfoot Clay		3.9	
	Clavellata	Clavellata	Red Beds *	2.0	
			Clay Band *	0.6	
			Chief Shell Beds *	2.1	
			Sandy Block *	2.4	
Middle Oxfordian	Osmington Oolite	Nodular Rubble		3.2	
		Shortlake		5.1	
		Upton		8.3	
	Redcliff	Bencliff Grit		6.7	
		Nothe Clay		12.0	
		Preston Grit		1.5	
Lower Oxfordian		Nothe Grit		9.0	
	Oxford Clay	Weymouth Member	Bowleaze Clay (containing Red Nodule Bed) *	14.5	
			Jordan Cliff Clay *	9.0	
			Furzedown Clay *	18.0	

* informal subdivisions (see text)

Figure 2.6 The complete stratal succession at the Osmington GCR site.



* informal subdivision – see text

Figure 2.7 The ammonite zones and subzones of the Oxfordian Stage showing the zonal range of the strata present at the Osmington GCR site.

eral dip of the succession is easterly, so that the beds young from west to east. However, faults and local steep dips interrupt the succession, which is partially repeated three times. Landslips and growth of vegetation mean that parts of the succession are rarely exposed or very difficult to access. Details of the various exposures are given below.

Oxford Clay Formation (Weymouth Member) (41.5 m)

S.S. Buckman (1923–1925) was the first to note the threefold subdivision of the 'Upper Oxford Clay' (now, following Cox *et al.* (1992), the Weymouth Member) in the Weymouth area. Wright (1986b) refined Buckman's work, and named the following informal subdivisons.

The Furzedown Clay, a mudstone containing pyritized *Cardioceras (Scarburgiceras) scarburgense* (Young and Bird) and *Quenstedtoceras* spp. now altered to limonite, is sometimes well exposed at the base of the cliff in the centre of the Redcliff Anticline at Shortlake (SY 716 818). Under favourable conditions the contact with uppermost Callovian mudstone containing *Q. (Lamberticeras) lamberti* (J. Sowerby) is exposed in the very centre of the structure. The higher part of the Furzedown Clay is hidden by grass and slipped clay. The maximum thickness is probably 18 m.

The Jordan Cliff Clay, comprising 1 m of fissile clays overlain by 8 m of tough, silty, blocky mudstone, was formerly well exposed at the type locality of Furzy Cliff (SY 698 817). However, much of this site was made inaccessible by the building of sea defences in 1985. A small exposure of silty clays containing *Gryphaea dilatata* J. Sowerby and *Modiolus bipartitus* J. Sowerby can be seen at present at the eastern end of the sea defences (Wright, 1986b), and the unit is well exposed on the northern side of Redcliff Point (SY 712 816), where well-preserved *Gryphaea dilatata* are very common.

The Bowleaze Clay (14.5 m) comprises a series of soft, plastic mudstones, which underlie the landslipped cliff between the sea defences and the holiday camp in Bowleaze Cove (SY 699 818–SY 702 819). Incursions of dark, carbonaceous, silty clay are common, and about the middle of the unit is the well-known Red Nodule Bed, a double row of red-weathering, sideritic concretions. The Bowleaze Clay has yielded an abundant fauna of cardioceratids and a perisphinctid fauna unique to Britain (Wright, 1986b, figs 3, 4; see Figs 2.11G–K). The holotypes of *Peltoceras (Peltomorphites) hoplophorous* (S. Buckman), *Cardioceras (Vertebriceras) altumeratum* Arkell and *Goliathiceras (Pachycardioceras) anacanthum* S. Buckman were collected here. The preservation of the ammonites is often superb. A small exposure of these clays, yielding *Cardioceras* spp., is seen in the low cliffs at the south-eastern end of Redcliff Point (SY 7125 8155).

Redcliff Formation (29.2 m)

There is no one, complete section through the Nothe Grit Member, but the full thickness is thought to be 9 m (Wright, 1986a). The base of the member is exposed at Ham Cliff (SY 712 817). The sharp, erosive junction

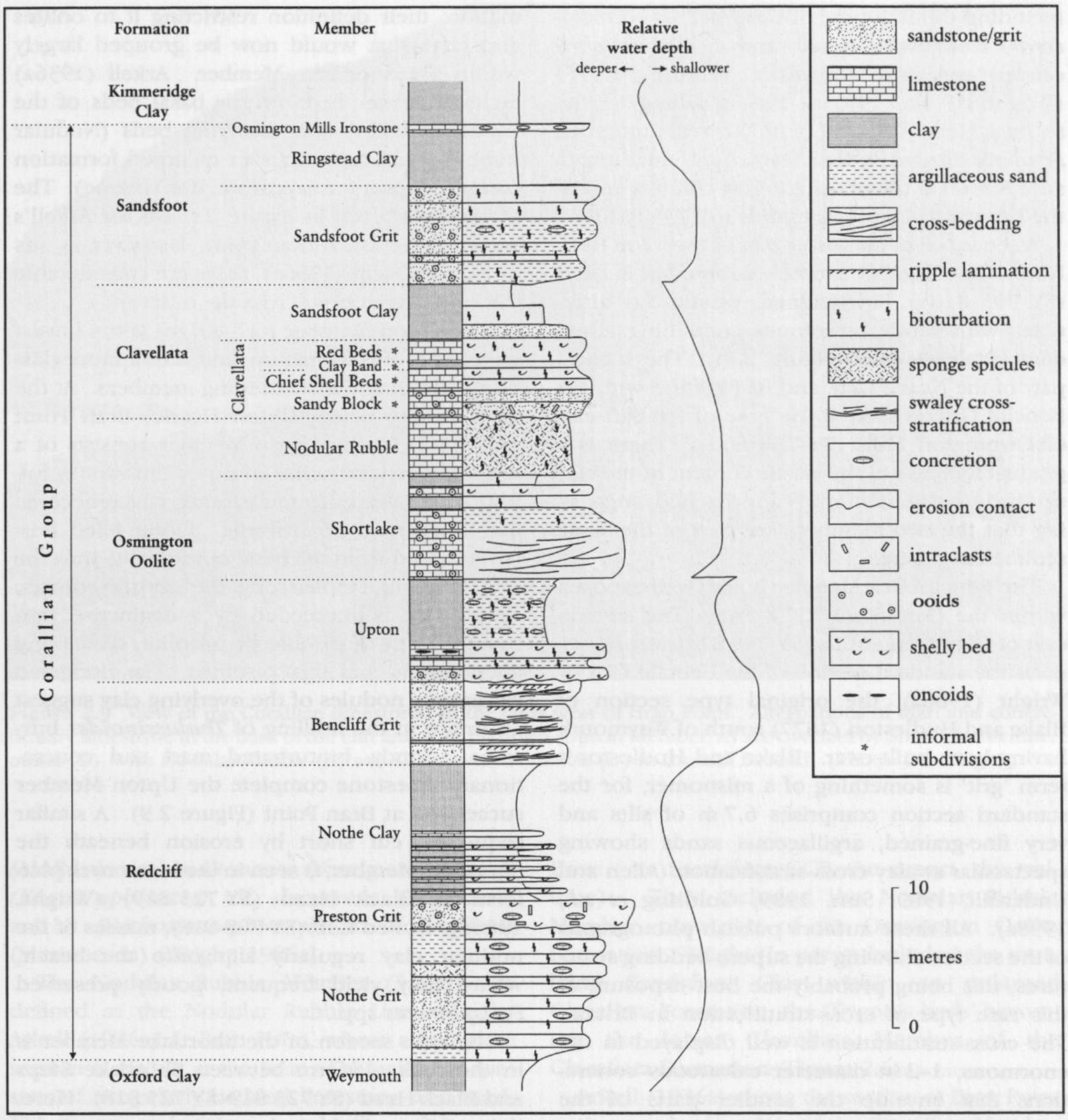


Figure 2.8 Log of the Corallian Group at Osmington, (after Sun, 1989, figs 6, 7, 10 and 13).

reveals the presence of a non-sequence between the uppermost Oxford Clay and this fine-grained, argillaceous sandstone. The upper two-thirds of the formation is exposed in the low cliffs west of Redcliff Point. Scattered concretions contain ammonites *(Cardioceras (Cardioceras) cordatum* (J. Sowerby), *C. (C.) persecans* S. Buckman (holotype) and *C.* spp.) preserved in honey-coloured calcite (Wright, 1986a). A small exposure of Nothe Grit occurs at Osmington Mills, immediately east of the slipway (SY 735 816).

The Preston Grit Member forms the highest 1.5 m of the low cliff extending from the Bowleaze Cove holiday camp to Redcliff Point (SY 704 818–SY 710 817). It consists in the main of medium-grained, shelly, calcareous sandstone, blocks of which weather out superbly on the upper shore section, revealing many bivalves, trace fossils and frequent ammonites, including the holotype of *Cardioceras (Cardioceras) cautisrufae* Arkell, and *C. (Subvertebriceras) zenaidae* Ilovaisky (Figure 2.11F) (Wright, 1986a, 1997). Blocks falling to the shore at Ham Cliff (SY 715 817) reveal numerous *Myophorella hudlestoni* (Lycett). A small exposure is seen at the top of the low cliff just east of the slipway at Osmington Mills (SY 735 816).

A sequence in the lower 8 m of the 12 m thick Nothe Clay Member can be examined at Redcliff (SY 706 818). Fine-grained, plastic clay alternates with sandy limestones containing abundant bivalve faunas (Figure 2.8). The highest part of the Nothe Clay, and its junction with the Bencliff Grit, is seen at the base of the cliff east of Osmington Mills (SY 738 814). There is a gradual increase in the clastic content of the clay upwards as the junction is approached, suggesting that the two members are part of the same sedimentary cycle.

The Bencliff Grit Member is very well exposed within the Osmington GCR Site. The section east of Osmington Mills (SY 740 814) was selected as the standard section of the Bencliff Grit by Wright (1986a), the original type section of Blake and Hudleston (1877) south of Weymouth having been built over. Blake and Hudleston's term 'grit' is something of a misnomer, for the standard section comprises 6.7 m of silts and very fine-grained, argillaceous sands showing spectacular swaley cross-stratification (Allen and Underhill, 1989; Sun, 1989; Goldring *et al.*, 1998a). All these authors publish photographs of the section showing the superb bedding structures, this being probably the best exposure of this rare type of cross-stratification in Britain. The cross-stratification is well displayed in the enormous, 1–2 m diameter calcareous concretions that envelop the sandier parts of the sequence. In between the concretions, the uncemented sandy beds have the distinct smell of heavy oil, showing that the rock was at one time an oil reservoir prior to the unroofing of the Weymouth anticline. Westwards, the fossil content of the Bencliff Grit becomes important, and in the rock platform beneath Redcliff (SY 708 818) there are many blocks consisting of Bencliff Grit concretions revealing excellent trace fossils (Fürsich, 1975), and occasional bivalves and ammonites (Wright, 1986a).

Osmington Oolite Formation (16.6 m+)

Blake and Hudleston (1877) originated this formation, their definition restricting it to oolites and clays that would now be grouped largely within the Shortlake Member. Arkell (1936a) included lower beds (sandy basal beds of the Upton Member) and overlying beds (Nodular Rubble Member) within an enlarged formation (see site report for Sandsfoot, this volume). The thicknesses given in Figure 2.6 are for Arkell's standard section at Bran Point. However, as was noted by Wright (1986a), there are considerable thickness variations across the outcrop.

The Upton Member (6.7–8.8 m) is the lowest member of this formation, and is of a more clastic nature than the succeeding members. At the type locality below Upton House, Bran Point (SY 742 813), the Upton Member consists of a regularly bedded series of sandy limestones followed by calcareous mudstones, which become increasingly sandy upwards. Oolite-filled burrows extend from the basal sandy oolite into the Bencliff Grit, emphasizing the abrupt contact. This oolite is succeeded by a distinctive thin development of pisolite or oncolite, containing abundant 10 mm algal pisoliths. The elongated calcareous nodules of the overlying clay suggest an origin in the infilling of *Thalassinoides* burrows. Sandy, bioturbated marl and concretionary limestone complete the Upton Member succession at Bran Point (Figure 2.9). A similar sequence, cut short by erosion beneath the Shortlake Member, is seen in the lower rock platform at Black Head (SY 725 819) (Wright, 1986a). At Red Cliff (SY 708 818), masses of the nodular clay regularly slip onto the beach, where they yield frequent, poorly preserved *Perisphinctes* spp..

The type section of the Shortlake Member is in the rock platform between Shortlake Steps and Black Head (SY 723 819–SY 725 818). Here, it is 10.4 m thick, and contains a spectacular spread of cross-bedded oolites with westerly dipping foresets up to 1 m high. These alternate with bioturbated oolites and clays, and are seen dipping steeply northwards in the rock platform. Correlation of individual beds is only possible over short distances. Thus, the cross-bedded oolite seen at Shortlake passes eastwards into level-bedded oolite with *Diplocraterion* burrows at Bran Point (Figure 2.9). The member is only 5.2 m thick here. Westwards, strongly cross-bedded oolite is seen at the top of Redcliff (SY 708 818). Profuse shale pellets indicate considerable scouring here. Occasional cardioceratids and perisphinctids are known, including *C.*

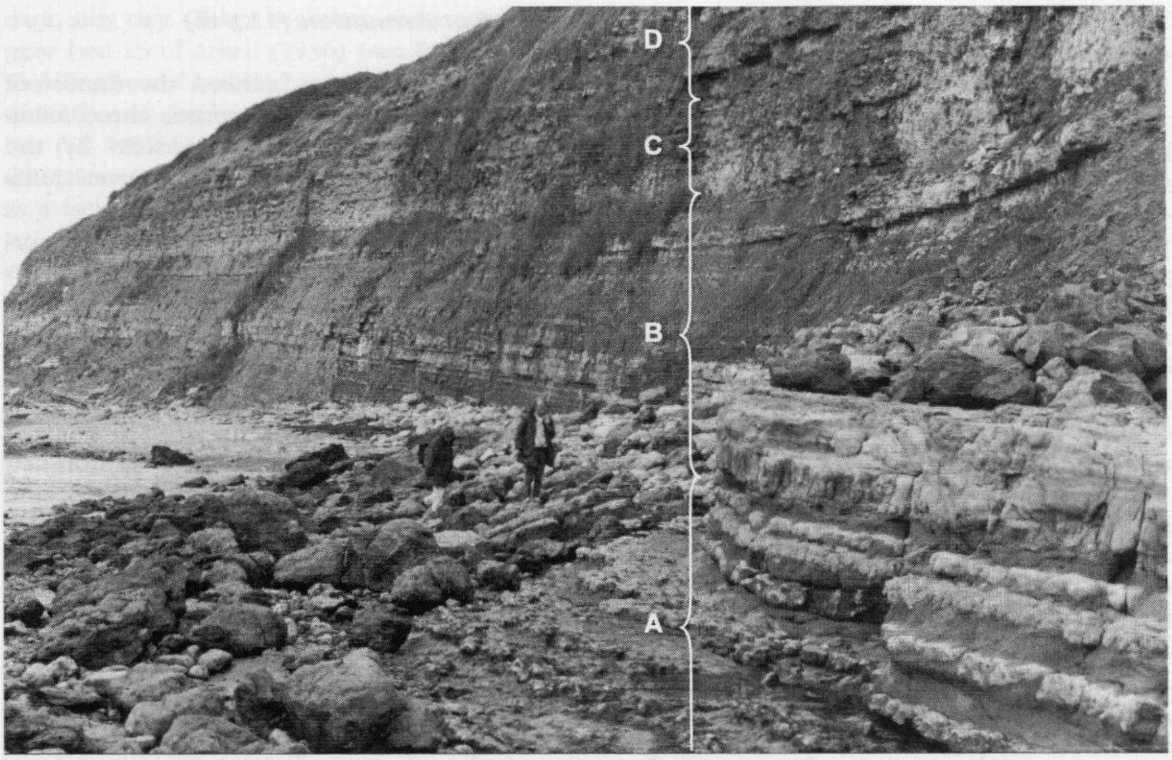


Figure 2.9 View of the Corallian limestones in the cliffs west of Bran Point. Alternations of marl and concretionary limestone in the base of the cliff and rock platform (Upton Member, A) are overlain by Shortlake Member oolite (B), with Nodular Rubble (C) and Clavellata Formation (D) in the cliff behind. (Photo: J.K. Wright.)

(Maltoniceras) maltonense (Young and Bird), *P. (Kranaosphinctes)* aff. *decurrens* (Buckman) and *P. (Dichotomosphinctes)* aff. *dobrogensis* (Simionescu) (Wright, 1986a).

The Nodular Rubble Member (3.2 m) was defined as the Nodular Rubble Limestone by Arkell (1936a) at Bran Point, where a complete section is visible at the base of the cliff. It consists of irregularly bedded limestone and marl. The limestone bands are markedly nodular and cream coloured, alternating with calcareous clay in 0.5 m bands. Excellent *Thalassinoides* burrow networks are seen in the low cliffs at Black Head, emphasizing the origin of the calcareous nodules as infilled *Thalassinoides* burrows. Important ammonite records include *Perisphinctes (Perisphinctes) pumilus* Enay and *P. (P.) parandieri* de Loriol (Wright, 1986a).

Clavellata Formation (11 m)

Blake and Hudleston (1877) originated this formation as the 'Trigonia-beds' of Weymouth. Their type section is presumably that at Castle Cove (see Sandsfoot GCR site report, this volume). They included the Nodular Rubble Member, now part of the Osmington Oolite Formation. Wright (in press) included the overlying Sandsfoot Clay within an enlarged Clavellata Formation, the 'Trigonia-beds' becoming the lower Clavellata Member of the Clavellata Formation (Figure 2.6).

Arkell (1936a) chose the section at Bran Point as the standard section of the Clavellata Member (7.1 m) (Figure 2.9). He gave detailed measured sections of most of the coastal exposures, these being later reprinted (Arkell, 1935–1948, 1947a). Wright (1986a) considered that the Bran Point section had deteriorated so much due to weathering that it was better to use the nearby Black Head section (SY 726 819) on which the following description is based. The Clavellata Member is there divided into four informal subdivisions as follows.

The Sandy Block (2.42 m) consists of four or five beds of grey, argillaceous limestone with immature ooliths and fine shell debris. Only a limited amount of quartz sand (5%) is present.

Scattered *Myophorella* sp. and *Perisphinctes* sp. occur. The junction with the underlying Osmington Oolite Formation is bored and erosive.

The Chief Shell Beds (2.07 m) are distinguished by the incoming in profusion of *M. clavellata* (Parkinson). There are five *M. clavellata*-rich layers containing largely dissociated valves preserved in impure oolite. Disseminated siderite weathers a pale reddish colour. Arkell (1936a) listed a prolific fauna including 20 species of bivalve from this member. Ammonites are common, Wright (1986a) recording *Amoeboceras glosense* (Bigot and Brasil), *Decipia lintonensis* Arkell and *Perisphinctes (Pseudarisphinctes)* spp..

The Clay Band consists of a 0.6 m thick incursion of silty, shelly, iron-rich clay.

The Red Beds (2.02 m) comprise layers of tough, grey, sideritic limestone weathering a bright red colour and giving this unit its very distinctive appearance. Softer, argillaceous oolite alternates with the sideritic limestones. Ammonites can be found quite commonly, sometimes exceptionally well preserved (Figure 2.11C, D). The following ammonite holotypes, figured by Arkell (1935–1948), were collected from the Dorset coast Red Beds: *Amoeboceras damoni* Spath, *Perisphinctes (Perisphinctes) cautisnigrae* Arkell, *P. (P.) uptonensis* Arkell, *P. (P.) boweni* Arkell, *P. (Arisphinctes) ringsteadensis* Arkell, *P. (A.) osmingtonensis* Arkell, *P. (Pseudarisphinctes) shortlakensis* Arkell, *P. (P.) damoni* Arkell, *P. (P.) pachachii* Arkell, *P .(P.) durnovariae* Arkell, *P. (Discosphinctes) cautisrufae* Arkell, *P. (D.) weymouthensis* Arkell, *P. clothieri* Arkell, *P. branensis* Arkell, and *P. dubius* Arkell.

The succession at Bran Point is very similar to that at Black Head, though the Chief Shell Beds are only half the thickness seen at Black Head.

The Sandsfoot Clay Member (3.9 m) shows a threefold sequence (Wright, 1998), comprising (i) sandy mudstone (0.85 m) overlain by (ii) bioturbated, sandy clay (1.45 m), and this by (iii) fine, silty clay (1.6 m). Bed (i) is highly fossiliferous, with numerous *Myophorella clavellata* (Parkinson) and *Gervillella aviculoides* (J. Sowerby), and ammonites including *Perisphinctes* sp. and *Decipia decipiens* (J. Sowerby). The higher beds, though less fossiliferous, yield frequent bivalves including *Goniomya literata* (J. Sowerby) and *Pleuromya uniformis* (J. Sowerby). There is at present no exposure at Bran Point.

Sandsfoot Formation (11.3 m)

Wright (in press) has revised the Sandsfoot Formation, which now comprises three members: the Sandsfoot Grit overlain by the Ringstead Clay and the Osmington Mills Ironstone (Figures 2.6 and 2.8).

The Sandsfoot Grit Member (7.35 m) is poorly seen in the cliffs at Black Head (SY 725 819) (Coe, 1995). The three subdivisions of Brookfield (1978) are present. Unit I comprises poorly cemented sand with occasional limonite ooids (0.95 m). This is overlain by soft, uncemented, clayey sand (Unit II, 3.9 m). Unit III comprises fine- to medium-grained, iron-rich sandstone, intensely bioturbated towards the top, with bivalves, limonite ooids and quartz pebbles (2.5 m). From this matrix, Wright (1986a) recorded *Amoeboceras rosenkrantzi* Spath and *Microbiplices anglicus* Arkell (Rosenkrantzi Zone). There is no exposure of Sandsfoot Grit at Bran Point at present. Wright (1986a) demonstrated that erosion beneath the overlying Ringstead Clay Member has attenuated the Sandsfoot Grit in the Osmington area.

The Ringstead Clay Member (3.5 m) was initially described as the Ringstead Waxy Clay by Arkell (1936a). At the type locality of the member at Ringstead Bay (SY 748 813), under favourable beach conditions, up to 1 m of pale grey, very fine-grained, calcareous mudstone can be seen. Fossils are few. Numerous fine carbonate laminae are not affected by bioturbation, and only occasional small, thin-shelled bivalves are present. Above this pale grey mudstone is 0.5 m of reddish, laminated, silty mudstone with siltstone lenses and numerous sideritic concretions and nodules. Arkell (1947a) recorded *Ringsteadia anglica* Salfeld from this horizon. Exposures of the Ringstead Clay (3.5 m) in the cliffs between Black Head and Osmington Mills at (SY 728 829) and (SY 732 818) again show fossiliferous mudstone containing in the upper part abundant orange-weathering ferruginous concretions. These lens-shaped concretions are very diagnostic of the member throughout Dorset.

The Osmington Mills Ironstone Member (0.48 m) was a term introduced for the highest Oxfordian beds by Brookfield (1978). At the type locality in the cliffs at (SY 733 818), the member comprises 0.2 m of limonite-oolite calcareous mudstone containing *Ringsteadia evoluta* Salfeld (Figure 2.11A) overlying 0.28 m of dark, silty clay. Taken together, these two comprise bed 25 of Arkell (1936) (see Figure 3.11). The Ringstead Coral Bed, exposed to a thickness of 0.16 m in the base of the cliffs in Ringstead Bay (SY 748 813) occupies the same horizon as the calcareous mudstone, and is now regarded as a facies of this part of the Osmington Mills Ironstone Member (Brookfield, 1978). The lateral transition from limonite-oolite calcareous mudstone facies into Ringstead Coral Bed facies is visible in Ringstead Bay between (SY 745 813) and (SY 747 813). The Ringstead Coral Bed contains tabular or foliaceous colonies of *Thamnasteria concinna* (Goldfuss). These are partly in life position, partly broken, bored or abraded, and set in a fine, micritic matrix along with occasional solitary *Thecosmilia annularis* (Fleming) and numerous bivalves. The latter include *Nanogyra nana, Lopha genuflecta* Arkell, *Astarte* sp. and *Chlamys nattheimensis* (de Loriol). Further coralliferous exposures of calcareous mudstone occur in the cliffs at Black Head (Coe, 1995).

Interpretation

The Oxford Clay is present in a variety of offshore marine facies laid down below the fair-weather wave base, though at a depth where the sediments were sometimes affected by storms. Thus, the fine, plastic, non-bituminous Furzedown Clay contains bottom-living forms such as *Gryphaea,* and cannot have been laid down at considerable depths under anoxic conditions. The Jordan Cliff Clay marks a shallowing, with an increase in the quartz sand content to 5%. A substantial epifauna is present, with numerous surface-dwelling bivalves. The Bowleaze Clay then marks a slight deepening, with the accumulation of pale, calcareous clays. Beds of carbonaceous, bioturbated, sandy clay mark moments when tropical storms swept rotting vegetation and quartz sand out to deeper water. A further deepening gave rise to the Red Nodule Bed. Surface-dwelling bivalves are not commonly preserved here, but deeper burrowing forms are. Siderite appears to have been precipitated as nodules in the topmost few centimetres of the sediment surface. Bivalves living within the sediment were thus preserved in life position without crushing. The conditions required for the precipitation of siderite within sediment are discussed in the Lynch Cove GCR site report (this volume).

The Corallian succession begins abruptly, the Nothe Grit resting on an eroded surface cut in indurated Oxford Clay. The sands of the Nothe Grit coarsen upwards, passing from offshore sandy silts into well-sorted, subtidal sands. Sedimentation of the Preston Grit then took place after a break and minor uplift. It marks the moment of transgression by the sea and is a shallow-water deposit that accumulated rapidly, with only a modicum of sorting under turbulent beach conditions.

Subsidence continued, and with the deeper sea there was the gradual change to deposition of the Nothe Clay. Shell sand was able to transgress repeatedly from the west, thick, shelly limestones being present at this level at Rodwell (see Sandsfoot GCR site report, this volume). Each of the shelly beds marks the building out of high-energy shell sand into a comparatively shallow sea in which clays were being deposited.

No satisfactory explanation of the mode of deposition of the Bencliff Grit has yet emerged. The situation is reviewed by Goldring *et al.* (1998a). Sedimentation occurred during five 'events'. Within each 'event', resting on an erosive surface, is a strongly cross-bedded sandy siltstone (Facies A). This is overlain by laminated silty mudstone or mudstone (Facies B), passing up into flaser-bedded mud and fine-grained sand (Facies C). The 'event' sequence is completed by fine-grained, ripple-laminated sandstone (Facies D). Not all event sequences are complete. U-shaped, infilled burrows of *Diplocraterium parallellum* extend down from Facies D.

Facies A represents a pulse of sediment introduced under environmental conditions differing from those normally pertaining. Absence of mud drapes rules out intertidal conditions, and Goldring *et al.* (1998a), while keeping their options open, suggest the possibility of a lagoonal setting. Facies A would require unidirectional currents bringing washover sands that would spill into the lagoon landward of a barrier island to the south or south-east. Facies B and C would mark the progression towards more open-water marine conditions, still lagoonal, and Facies D would then represent shallow marine sedimentation in a storm-affected environment. During calmer conditions the area was rapidly colonized by bivalves (*Myophorella*) and by gastropods which left feeding trails (*Gyrochorte*).

The Osmington Oolite Formation marks a

return to predominantly carbonate sedimentation. The oolite, pisolite and concretionary limestone of the Upton Member contain some quartz sand, but also considerable amounts of clay, indicating offshore conditions away from winnowing currents. The sequence becomes progressively deeper, with deposition of nodular clay below the fairweather wave base. Ammonites had free access, and formed the sites for growth of some of the concretions. There is then a return to sandy, bioturbated marl laid down in shallower water.

The Shortlake Member is predominantly oolitic. Conditions were lagoonal or intertidal, with fine clays alternating with cross-bedded, sometimes heavily bioturbated, oolite. The strongly cross-bedded oolite was laid down as an ooid delta that migrated across the area. The cross-bedding dips to the west or south-west. This implies that to the north-east lay the lagoonal area wherein sea water was evaporated and supersaturated in calcium carbonate ready to precipitate as ooids in tidal channels. The Nodular Rubble was laid down after a break, under much quieter, offshore shelf conditions favouring the growth of the sponge *Rhaxella*.

The marine transgression that heralded Upper Oxfordian sedimentation in the area is marked by a marine bench cut into the Nodular Rubble, with substantial borings and colonization by burrowing organisms. This Clavellata Formation transgression was gradual and persistent, so that the sediments were deposited in progressively deeper water. The shallow-water sandy carbonates of the Sandy Block thus pass up into the prolifically fossiliferous *Myophorella* shell beds, the basis of the *Myophorella clavellata* association of Fürsich (1977). The association is dominated by shallow-burrowing and surface-dwelling bivalves, which lived in fine-grained, offshore sediment. The shells were brought together into huge shell banks during storms, with the valves frequently dissociated and convex upwards. Finally, the clay and ferruginous micrite of the Clay Band and the Red Beds point to deeper-water conditions below the wave base, with *Myophorella* frequently preserved with both valves together.

The basal Sandsfoot Clay is markedly sandy, averaging more than 50% fine sand, and is more properly called a sandy mudstone. The basal bed marks the rejuvenation of source areas prior to a more substantial transgression, which led to deeper-water marine clays being laid down over the whole area. These clays are seen particularly well at Black Head, where there is a progressive fining upwards.

After a prolonged period for which there is no sedimentary record (Figure 2.7), south Dorset was subject to renewed uplift, most marked in the present area. Erosion of the Sandsfoot Clay took place, so that some 10 m of beds present in the Fleet Lagoon area are absent here (Wright, 1998). Because of its cross-cutting relationship, the overlying Sandsfoot Grit bears no relation to the Sandsfoot Clay in the manner of a shallowing-upwards cycle. Much of the Sandsfoot Grit is quite coarse grained, and appears to be built up of shelly beach sands, which alternate with pebbly chamositic sands possibly laid down in lagoonal areas in between beach bars.

The Ringstead Clay, with its fine, unbioturbated, laminated sediment and limited fauna of thin-shelled bivalves, suggests deposition in shallow, sheltered, lagoonal conditions, possibly hypersaline. The presence of siderite concretions implies a lack of marine circulation. In these circumstances the bottom water becomes depleted in sulphate, and siderite forms in preference to pyrite. Such conditions are toxic to bottom life. Fully marine conditions were re-established in the uppermost Oxfordian, with deposition of the Osmington Mills Ironstone and Ringstead Coral Bed. The sedimentation rate was very slow. Encrusting bivalves and serpulids proliferated to the west, with the input of limonite ooids, and eastwards at Ringstead the input of clay and clastic grains was sufficiently low that for a short period the shallow sea floor was colonized by both encrusting and phaceloid corals. This was a deep water accumulation, below the fairweather wave base. Foliaceous and branching corals were surrounded by areas of lime mud containing a prolific bivalve fauna. The coral–bivalve fauna was frequently reworked, but by currents not sufficiently strong to damage it, or to winnow away the lime mud.

Numerous stratigraphical breaks have been recognized within the Osmington Corallian attesting to episodes of intra-Oxfordian erosion. These relate to tectonic instability within the Wessex Basin, and have been used locally as marker horizons (Talbot, 1973a). The discontinuities, of which at least nine are recorded at Osmington (Wright, 1986a), lie at irregular stratigraphical intervals between highly variable lithologies. Many authors have tried to see a pattern of cyclic sedimentation, the cycles bounded by erosion surfaces (Arkell, 1947a; Talbot, 1973a; Sun, 1989). The cycle generally begins with an arenaceous unit, passing up into a clay unit that is frequently followed by oolitic limestone. British Jurassic strata often show evidence of such sedimentary cycles, which may be impersistent laterally or incomplete vertically. They are often interpreted as representing successive eustatic transgressions and regressions, although Wilson (1968b) has argued that they have more significance in terms of non-carbonate clastic deposition than the eustatic changes in sea level preferred by Hallam (1978). The unstable tectonic environment of southern England, witnessed by the many localized periods of uplift and erosion, suggests strongly that the cycles owe their origin to variable rates of tectonic subsidence.

Newell (2000) has taken the five principal erosion surfaces that bound the four formations into which the Corallian Group is divided, and produced a sequence stratigraphical interpretation of the Dorset succession. This is set out in Figure 2.10.

Sequence 1 (Redcliff Formation)

The Nothe Grit, a distal shelf clastic deposit, sits a little uneasily as a lowstand systems tract at the base of Sequence 1. However, it is overlain by a clear transgressive systems tract comprising the Preston Grit and limestones of the Nothe Clay. The Preston Grit is interpreted as part of a transgressive sheet forming in a mid-ramp setting. This system was drowned around maximum flooding, and covered by mudstone containing bored micrites and bioclastic and sideritic limestones typical of the condensed zone formed under very low sedimentation rates around peak transgression. The highstand systems tract is represented by the fine mudstones of the upper part of the Nothe Clay.

The falling stage systems tract is represented by the Bencliff Grit. The sharp-based sandstone bodies of this member are typical of those formed under the control of relative sea-level falls. Here, the shoreface zone of wave scour moved basinwards, producing a regressive surface of erosion. This erosion surface is overlain by thin sand bodies that are smeared across the shoreface in response to falling sea level. Wave scour reworks and concentrates sufficient sand in an onshore direction to develop a prograding sand body.

Sequence 2 (Osmington Oolite Formation)

The Upton Member represents the transgressive systems tract, with sandy, bioclastic limestone overlain by deeper-water nodular clay. The highstand systems tract is dominated by oolitic limestone. Highstands are generally the optimum time for carbonate production, because erosion of clastic sediment is at a minimum, and the area of shallow marine carbonate production has reached its maximum extent. The occurrence of trough and planar cross-bedding, mud drapes and tidal scours indicates the importance of tidal processes in ooid formation.

Newell includes the Nodular Rubble Member in Sequence 2. Though it obviously formed at a highstand, it appears to have formed during a transgressive event situated in between Newell's Sequence 2 and Sequence 3. This event is represented across much of England by the Coral Rag Member (Wright, in press). In Yorkshire, there is often a transgressive systems tract (shelly, coralliferous oolite), overlain by a high systems tract (micritic, coralliferous limestone) (see site report for Wath Quarry, this volume).

Sequence 3 (Clavellata Formation)

The transgressive systems tract follows the same pattern as in the underlying sequences, with sandy, bioclastic wackestone (Sandy Block) overlain by high-energy, skeletal-ooidal intraclast grainstone (Chief Shell Beds). The finer-grained Red Beds mark a maximum flooding condensed interval.

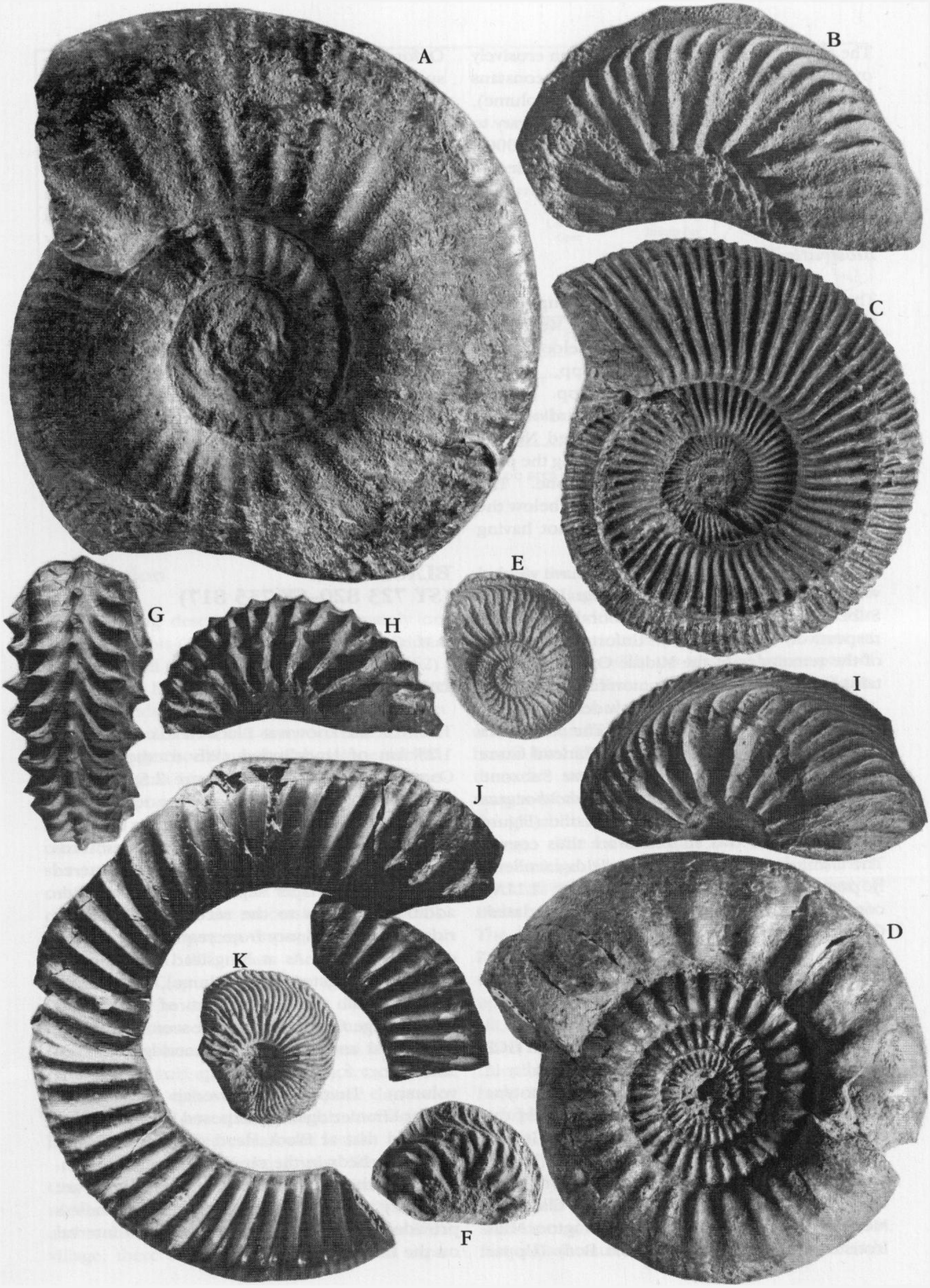
The highstand systems tract comprises calcareous, intensely bioturbated, sandy mudstone (Sandsfoot Clay Member), passing up, in beds only preserved in the Fleet Lagoon area (Wright, 1998), into fine clays with well-preserved, siderite-infilled bivalves and ammonites, a facies reminiscent of the Weymouth Member.

Sequence 4 (Sandsfoot Formation)

Sequence 4 as defined at Osmington begins with the medium-grained, bioturbated sands of the Sandsfoot Grit Units I and II (transgressive systems tract), followed by the phosphatic chamosite oolite sands of Unit III (condensed stage), the Ringstead Clay (highstand systems tract) and Osmington Mills Ironstone (condensed interval or falling stage systems tract).

Figure 2.10 Sequence stratigraphical interpretation of the Corallian sequence at the Osmington GCR site (after Newell, 2000, fig. 2).

Figure 2.11▸ Selection of Oxfordian ammonites from the Dorset coast Oxfordian exposures. (A) ***Ringsteadia evoluta*** Salfeld, Osmington Mills Ironstone, Black Head, J44969, ×0.95. (B) ***Amoeboceras glosense*** (Bigot and Brasil), Clavellata Member, Black Head, D/C/25, ×0.95. (C) ***Perisphinctes*** (***Perisphinctes***) ***uptonensis*** Arkell, Clavellata Member, Black Head, DC42, ×0.80. (D) ***P.*** (***Pseudarisphinctes***) ***pachachii*** Arkell, Clavellata Member, Black Head, D/C/46, ×0.48. (E) ***Amoeboceras ilovaiskii*** (M. Sokolov), Clavellata Member, Black Head, D/C/29, ×1. (F) ***Cardioceras*** (***Subvertebriceras***) ***zenaidae*** Ilovaiski, Preston Grit, Redcliff, D/C/90, ×1. (G, H) ***Cardioceras*** (***Vertebriceras***) ***quadrarium*** S. Buckman. Red Nodule Bed, Furzy Cliff, D/O/35, ×1. (I) ***Cardioceras*** (***Cardioceras***) ***costicardia*** S. Buckman, Red Nodule Bed, Furzy Cliff, D/O/20, ×1. (J) ***Perisphinctes*** (***Dichotomosphinctes***) sp. Weymouth Member, Bowleaze Clay, Furzy Cliff, D/O/41, ×0.58. (K) ***Cardioceras*** (***Scarburgiceras***) ***praecordatum*** Douvillé, East Fleet section, just north-west of the Lynch Cove GCR site, D/O/1, ×1. (Photos: (A, C, D) K. D'Souza; (F), K. Denyer; (B, E, G–K), J.K. Wright. Collections: Prefix 'D', J.K. Wright collection; prefix 'J', Sedgwick Museum Collection, Cambridge.)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The Osmington Mills Ironstone is then erosively overlain by the early Kimmeridgian Inconstans Bed (see site report for Ringstead, this volume), the beginning of the next sequence. Contrary to the view expressed by Newell (2000), Kimmeridgian strata should not be included in Sequence 4.

Biostratigraphy

The Osmington site is also of great importance to ammonite biostratigraphers. The Weymouth Member of the Oxford Clay has yielded excellently preserved *Cardioceras* spp. (Figure 2.11G–I, K) and *Perisphinctes* spp. (Figure 2.11J) (Costicardia Subzone). The cardioceratid fauna of the Costicardia Subzone Red Nodule Bed was listed by Arkell (1945) as being the principal fauna illustrative of this subzone. The perisphinctid fauna, which occurs just below the Red Nodule Bed, is so far unique, not having been described for any other locality.

The Nothe Grit and Preston Grit have yielded well-preserved ammonites of the Cordatum Subzone and the early Vertebrale Subzone respectively (Figure 2.11F). Unfortunately much of the remainder of the Middle Oxfordian contains few well-preserved ammonites.

The Upper Oxfordian includes two very important ammonite faunas. The Clavellata Member yields the excellent perisphinctid fauna typifying the Sub-Boreal Cautisnigrae Subzone (Figure 2.11C, D), and numerous *Amoeboceras* typifying the Boreal Glosense Subzone (Figure 2.11B, E). The two subzones are thus coeval. The Osmington Mills Ironstone yields excellently preserved *Ringsteadia* spp. (Figure 2.11A), comprising the type fauna of the latest Oxfordian Evoluta Subzone.

Conclusions

The Oxfordian exposures at the Osmington GCR site are superior to those at any other locality in England. The site incorporates the stratotype localities for 11 formations and members of the Oxford Clay Formation and Corallian Group, including the Weymouth Member (Lower Oxfordian), the Preston Grit and Osmington Oolite (Middle Oxfordian) and the Clavellata Member, Ringstead Clay and Osmington Mills Ironstone (with Ringstead Coral Bed) (Upper Oxfordian). The site also displays the best exposures of the Nothe Grit (Lower Oxfordian) and the Nothe Clay and Bencliff Grit (Middle Oxfordian), whose type localities lie within the boundary of the neighbouring Sandsfoot GCR site (this volume).

The monographs of Arkell concerning both the bivalve (1929–1937) and ammonite faunas (1935–1948), respectively, emphasize the key biostratigraphical importance of the whole Oxfordian invertebrate assemblage that occurs at Osmington. The holotype specimens of no less than 46 species of bivalve and ammonite were collected here. Of the 15 constituent subzones of the Sub-Boreal subzonal scheme, 12 are represented by ammonite-bearing strata at the site. Both the Oxford Clay and the Corallian Group are of exceptional interest here due to the wealth and variety of sediments and sedimentary structures that they display and the richness and diversity of the Oxfordian faunas.

BLACK HEAD (SY 723 820–SY 735 817)

B.M. Cox

Introduction

The GCR site known as Black Head covers about 1.25 km of landslipped cliffs to the west of Osmington Mills, Dorset (Figure 2.5). Viewed from there, the landslips appear to form an almost continuous black cliff that gives the locality its name. West of Black Head and eastwards to Osmington Mills village, there are scattered exposures in smaller slip faces, which provide additional details to the section on the main ridge. These can vary from year to year as new cliff falls occur. As at Ringstead Bay (see site report for Ringstead, this volume), the sections here expose the lower part of the Lower Kimmeridge Clay, which is not seen in the type sections at and adjoining Kimmeridge Bay (see site report for Tyneham Cap–Hounstout, this volume). There is little overlap between the Lower Kimmeridge Clay exposed in Kimmeridge Bay and that at Black Head (Figures 2.12 and 2.14); the beds in the range of overlap are considerably thinner at the latter locality and are generally poorly exposed but they nevertheless provide the best sections through this interval on the Dorset coast.

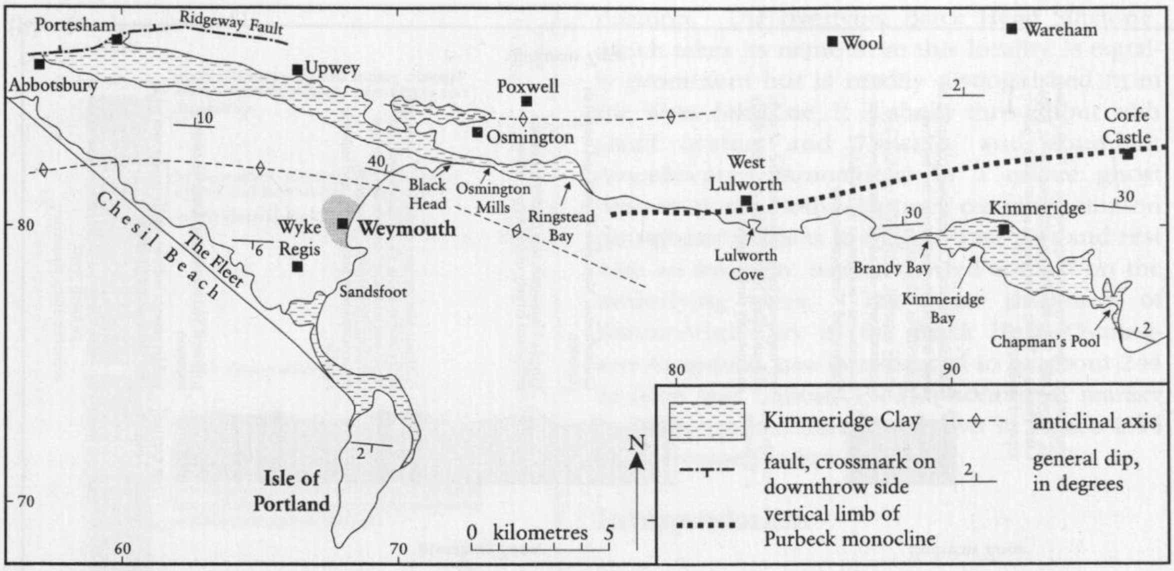

Figure 2.12 Kimmeridge Clay outcrops in the Dorset type area (after Cox and Gallois, 1981, fig. 1).

Description

The following description is based mainly on Cox and Gallois (1981). Earlier citations include those of Arkell (1933, 1947a) and Ziegler (1962). Viewed from the beach, there are few prominent marker bands visible in the cliffs of the main ridge at Black Head but two or three tabular beds or dogger horizons of cementstone, including the Virgula Limestone (a soft muddy limestone composed almost entirely of the oyster *Nanogyra virgula* (Defrance)) and the Nannocardioceras Cementstone (a nodular cementstone with the ammonite *Amoeboceras (Nannocardioceras)* preserved in uncrushed, translucent calcite), divide the succession (Figure 2.13). Dips are generally steep throughout the section, ranging from 80° near the base of the Kimmeridge Clay, to 50°–60° in the upper part. Camber and landslip add to the difficulties of making accurate thickness measurements. Much of the lower part is obscured by a thin crust of weathered clay but in dry weather this can be readily cleared away to expose clean sections of largely unweathered material, often with beautifully preserved calcareous fossils.

Small exposures of the lowest Kimmeridge Clay occur for about 300 m on the western side of Black Head (SY 7259 8192–SY 7229 8198), and to the east, almost as far as Osmington Mills village, there are a number of adjacent exposures in the cliffs on the eastern edge (SY 7336 8186) of a large landslip. Although complicated by faulting and locally steep dips, these provide an almost continuous section from the base of the Kimmeridge Clay up into the upper part of the Eudoxus Zone. The basal Kimmeridgian zones are often well displayed here as well as in a fault-bounded mass of Kimmeridge Clay at beach level (SY 7342 8174) (Figure 2.5) where there are steep (70°–80°) dips. The northern margin of the outcrop here shows clays low in the Mutabilis Zone faulted against the Corallian Group. The boundary of the latter with the Kimmeridge Clay is well exposed. Earlier accounts of the boundary beds include those of Blake and Hudleston (1877) and Arkell (1936a). The basal bed of the Kimmeridge Clay (and Kimmeridgian Stage) is the Inconstans Bed, which is a dark grey, intensely bioturbated clay up to *c.* 0.4 m thick with wisps and burrowfills of silt, fine-grained sand and scattered limonite ooids (from the underlying Osmington Mills Ironstone) in its lower part. Phosphatic pebble beds occur at the base and 0.3 m above the base; phosphatized serpulids, the gastropod *Pleurotomaria*, the bivalves *Goniomya*, *Pholadomya* and *Pleuromya*, the eponymous gastropod *Torquirhynchia inconstans* (J. Sowerby) and the ammonite *Pictonia* occur in both pebble beds and throughout the intervening clay. These forms also occur as crushed shells, together with

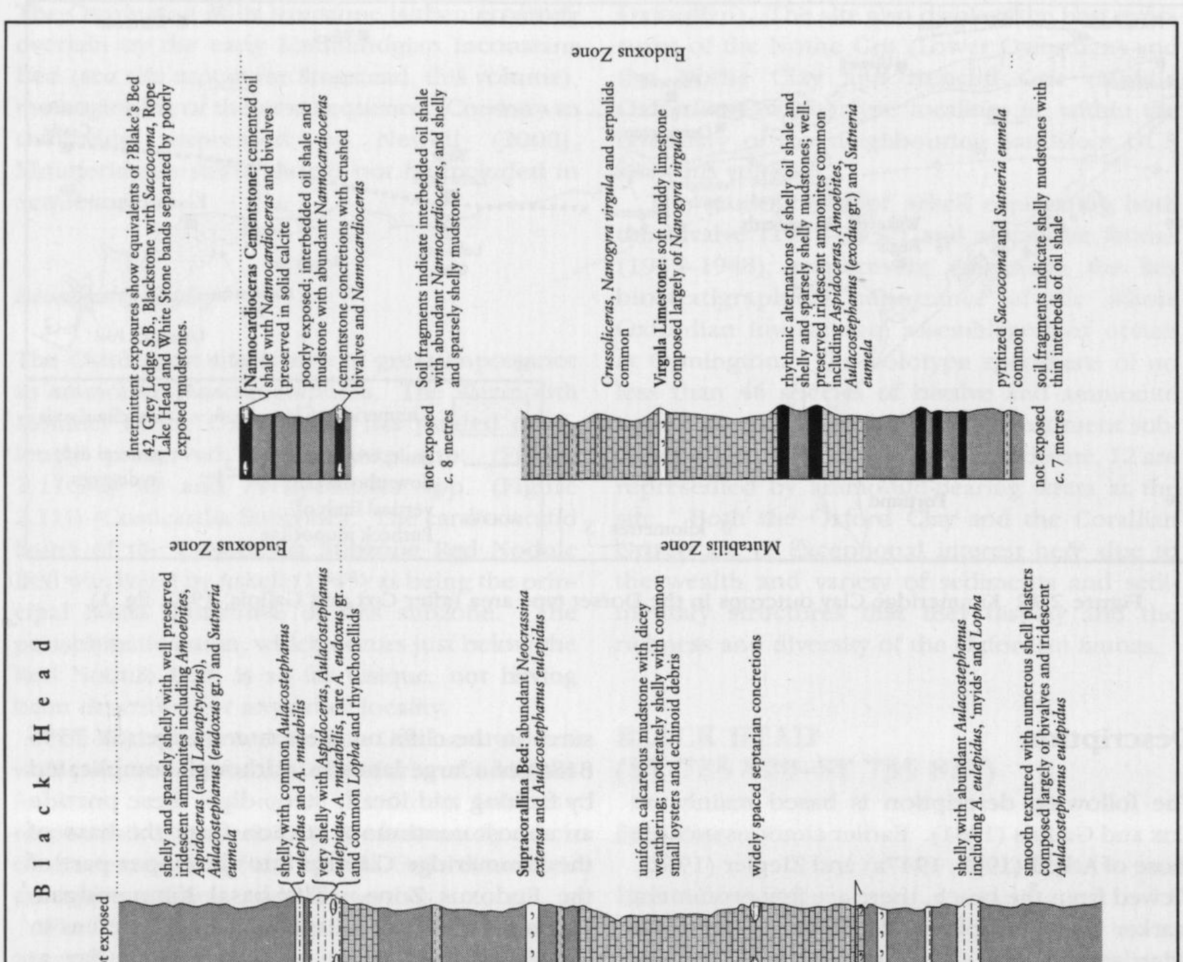

Figure 2.13a Graphic sections of the lower part of the Kimmeridge Clay at Black Head–Osmington Mills (SY 7239 8195, SY 7259 8192–SY 7258 8200, SY 7336 8186 and SY 7342 8174). (After Cox and Gallois, 1981, pp. 33–4.)

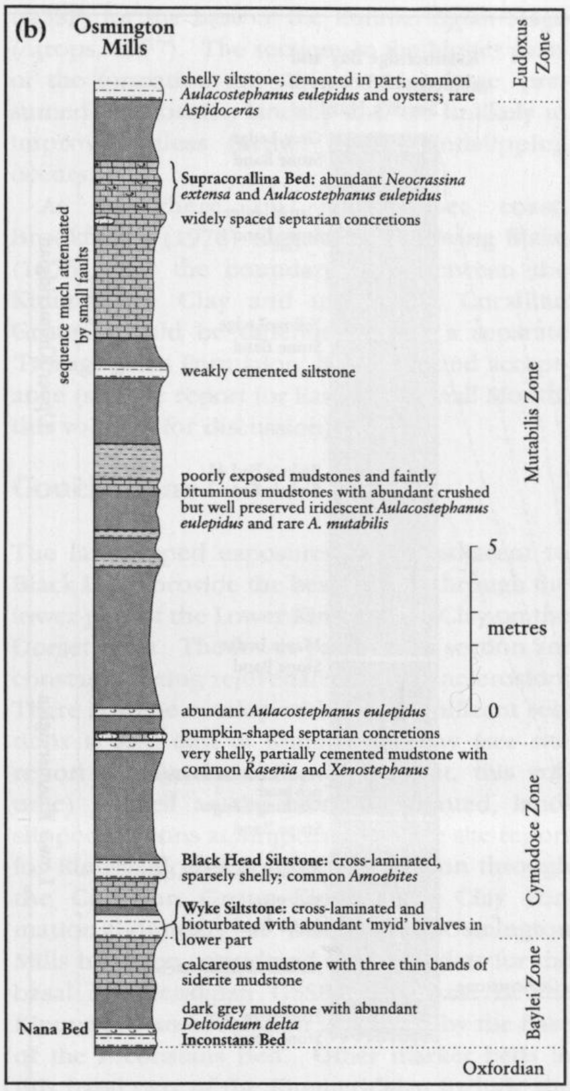

Figure 2.13b Graphic section of the lower part of the Kimmeridge Clay at Osmington Mills (SY 7342 8174). (After Cox and Gallois, 1981, pp. 33–4.)

Chlamys (as clay casts), nests of *Lopha*, and *Trigonia*. This part of the succession can be matched in detail with that at Ringstead Bay (see Figures 2.14, 2.23), although at Black Head and Osmington Mills, a shelly, ooidal ironstone (Osmington Mills Ironstone) replaces the Ringstead Coral Bed at the top of the underlying Oxfordian. A little higher in the basal beds of the Kimmeridge Clay, the Wyke Siltstone forms a prominent hard band and line of seepage. It consists of intensely burrowed, finely cross-laminated, muddy quartz silt, crowded in its lower part with bivalves, particularly 'myids' in growth position. The overlying Black Head Siltstone, which takes its name from this locality, is equally prominent but is readily distinguished from the Wyke Siltstone; it is shelly throughout with small oysters and *Thracia*, and abundant *Amoeboceras (Amoebites)* in a calcite ghost preservation. Both siltstones contain common phosphatic pebbles in their lowest part and rest with an irregular, interburrowed contact on the underlying clays. The total thickness of Kimmeridge Clay in the Black Head–Osmington–Ringstead area is estimated to be about 244 m (Cox and Gallois, 1981). Additional marker beds recognized here are shown in Figure 2.14 and discussed below.

Interpretation

The marker beds recognized in the Kimmeridgian succession at Black Head and Osmington Mills enable correlation with other sections in the Dorset type area (Figure 2.14) and further afield. These are, from below, the Inconstans Bed, Nana Bed (rich in the small oyster *Nanogyra nana* (J. Sowerby) and serpulids), Wyke Siltstone, Black Head Siltstone, Supracorallina Bed (pale calcareous mudstone with abundant *Neocrassina extensa* (Phillips) (formerly *Astarte supracorallina*)), Virgula Limestone, Nannocardioceras Cementstone, ?Blake's Bed 42, Grey Ledge Stone Band, Blackstone (with tiny pyritized plates of the pelagic crinoid *Saccocoma*) and the coccolith-rich White Stone Band (Figure 2.14). Together with the recorded ammonite faunas, these substantiate a zonal succession through the greater part of the Kimmeridgian Stage. As elsewhere in southern and eastern England, minor erosion surfaces occur at the bases of the Baylei, Cymodoce, Mutabilis and Eudoxus zones, although, with the possible exception of the Baylei Zone, these have not yet been formally defined in terms of their base in a type section. Cox and Gallois (1981) believed that the erosion surfaces could be regarded, for all practical purposes, as isochronous. The sections in the Lower Kimmeridge Clay, the lower parts of which are constantly being rejuvenated by marine erosion, are particularly important. The Kimmeridgian Boundary Working Group of the International Subcommission on Jurassic Stratigraphy (ISJS) has considered a section through the base of the Kimmeridge Clay here as a candidate Global Stratotype Section and Point

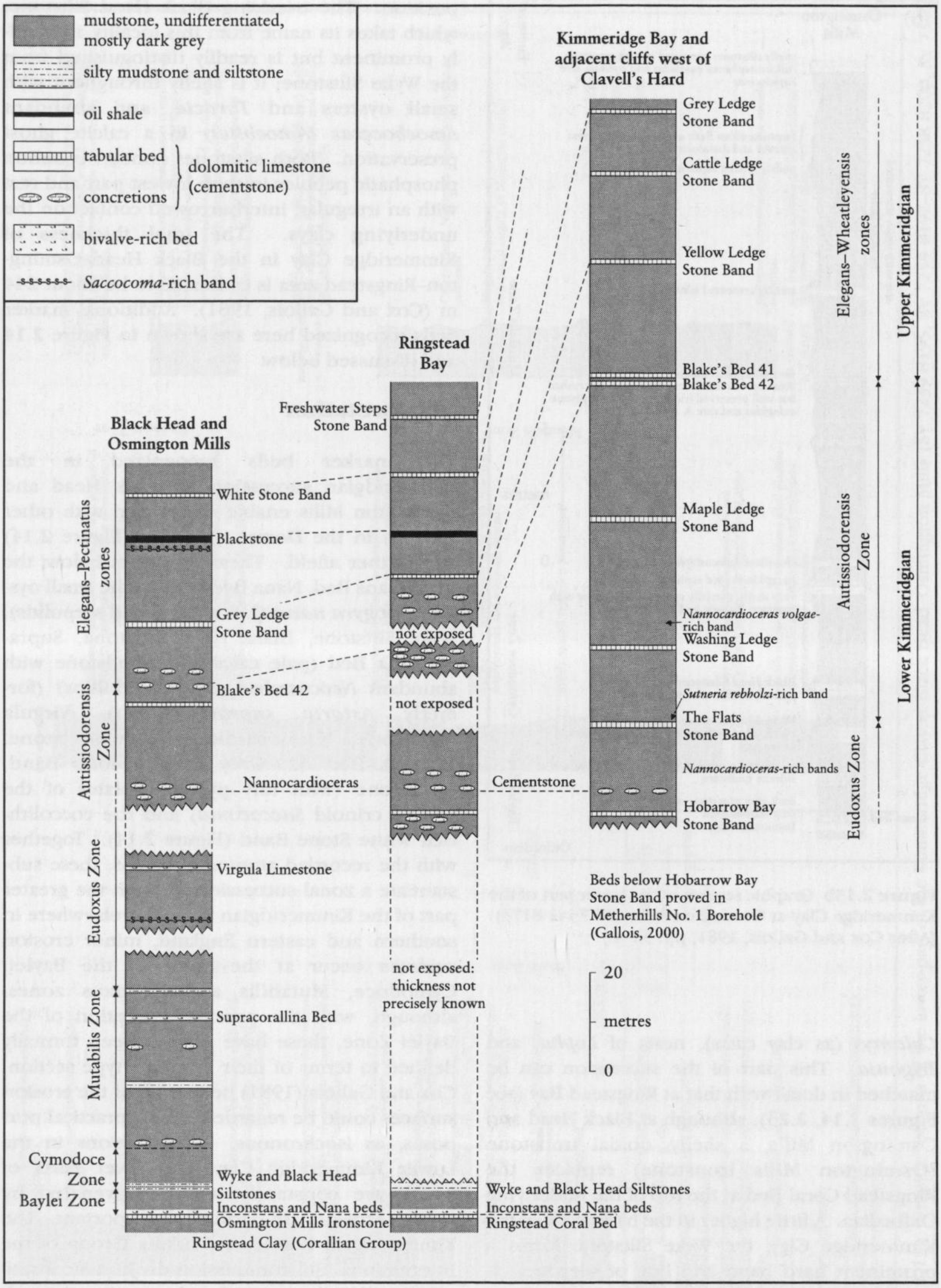

Figure 2.14 Correlation between the main sections of Kimmeridge Clay on the Dorset coast. Youngest zones not shown. (After Cox and Gallois, 1981, fig. 5.)

(GSSP) for the base of the Kimmeridgian Stage (Atrops, 1997). The sections in the higher parts of the formation are adjacent to a large, presumed Pleistocene, landslip and are unlikely to improve unless further major landslipping occurs.

As elsewhere on the Dorset coast, Brookfield's (1978) suggestion, following Blake (1875), that the boundary beds between the Kimmeridge Clay and underlying Corallian Group should be differentiated as a separate 'Passage Beds Formation' has not found acceptance (see site report for East Fleet–Small Mouth, this volume, for discussion).

Conclusions

The landslipped exposures at and adjacent to Black Head provide the best section through the lower part of the Lower Kimmeridge Clay on the Dorset coast. The lower parts of the section are constantly being rejuvenated by marine erosion. There is some overlap with the magnificent sections at and east of Kimmeridge Bay (see site report for Tyneham Cap–Hounstout, this volume) as well as the more fragmented, landslipped sections at Ringstead Bay (see site report for Ringstead, this volume). A section through the Corallian Group–Kimmeridge Clay Formation boundary at Black Head–Osmington Mills has been considered as a candidate for the basal Kimmeridgian GSSP. The base of the Kimmeridgian succession is marked by the base of the Inconstans Bed. Other marker beds in this basal part of the Kimmeridgian include the Wyke and Black Head siltstones, which can also be seen in the coastal sections south of Weymouth (see site report for East Fleet–Small Mouth, this volume) but only fortuitously at Ringstead Bay (see Figure 2.23). The locality is thus an important one for regional, national and, most importantly, international stratigraphical studies.

RINGSTEAD (SY 751 813–SY 766 811)

B.M. Cox

Introduction

The Kimmeridgian GCR site at Ringstead Bay, Dorset (Figures 2.5 and 2.12), comprises mainly unconnected small cliff exposures of Kimmeridge Clay separated by landslip. The lower part of the formation is poorly exposed although for many years an exposure of the basal beds here has been the recommended basal boundary stratotype for the Kimmeridgian Stage (George *et al.*, 1969; Morton, 1974; Cox and Sumbler, 1994). Above the boundary beds, Arkell (1933, 1947a, 1949, 1951), who spent many of his vacations in a chalet here (Cox, 1958; House, 1989), described most of the sections that were available between about 1930 and 1950, and suggested that they could be correlated with one another to provide an almost continuous succession from the Baylei Zone to the lower Eudoxus Zone. A less interrupted Upper Kimmeridgian succession includes a number of marker beds enabling correlation with the type sections east of Kimmeridge Bay (see site report for Tyneham Cap–Hounstout, this volume).

Description

The degree and quality of exposure of Kimmeridgian strata at Ringstead Bay varies from year to year with the state of the beach and the landslips. The following description is based largely on Cox and Gallois (1981) who estimated that the thickness of the Lower Kimmeridge Clay was of the order of 95 m, much of which was either unexposed or too damaged by landslip to permit accurate measurement (Figure 2.14). The boundary of the Kimmeridge Clay with the underlying Ringstead Coral Bed, the topmost bed of the Oxfordian, was recorded by Waagen (1865), Blake and Hudleston (1877), Salfeld (1914), Arkell (1933, 1936, 1947a), Brookfield (1978) and Cox and Gallois (1981) (see Figure 2.23). According to Arkell (1933), the lowest Kimmeridgian beds could be conveniently studied in the low cliffs for about 1.5 km along the west side of the bay but even within the time span of Arkell's published work, the sections, including that illustrated by Arkell (1933, pl. 21) and later recommended as the boundary stratotype, had deteriorated and soon became largely obscured. In the late 1970s, the boundary was visible in only two small and degraded landslipped sections below the western end of Ringstead village (SY 7478 8139 and SY 7486 8137). At other times, for example in 1990, 1991 and 1996 following winter storms, there have been much better exposures of the basal Kimmeridge Clay in the low grassy cliffs

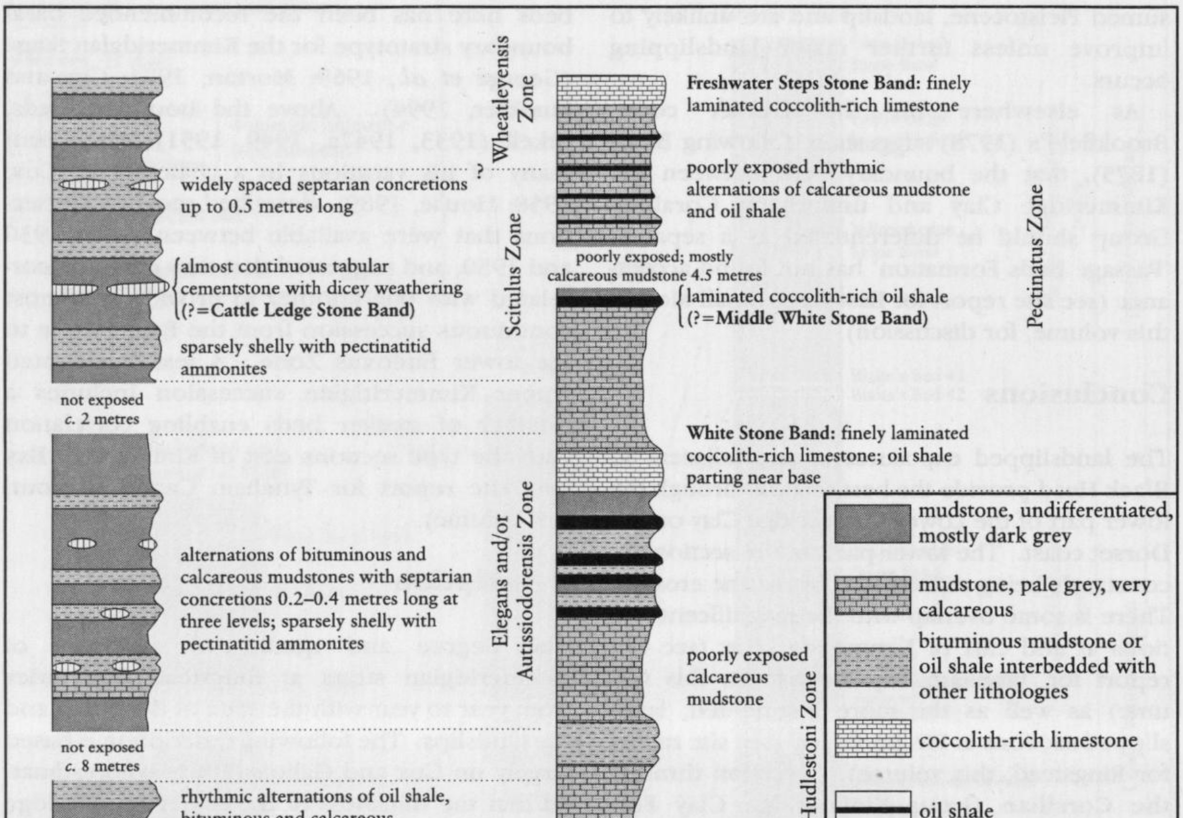

Figure 2.15 Graphic section of the Eudoxus–Pectinatus zonal interval at Ringstead Bay (SY 7619 8147, SY 7606 8147 and SY 765 813). (After Cox and Gallois, 1981, p. 35.)

and foreshore to the east and west of the slipway, but much of the exposure east of the slipway was later compromised by coastal protection work along some 30 m of the cliff (Anon, 1995). Following the storms, local collectors were able to build up substantial collections of Upper Oxfordian and Lower Kimmeridgian ammonites (J.K. Wright, pers. comm.). Eastwards from here, the next exposure reported by Cox and Gallois (1981) as being worthy of measurement is in the Eudoxus Zone. The upper part of the latter zone up to about the middle of the Autissiodorensis Zone was reported by these authors in two small overlapping sections (SY 7619 8147 and SY 7606 8147) but the Lower–Upper Kimmeridgian boundary was obscured by slipped material (Figure 2.15). Cox and Gallois (1981) measured the Upper Kimmeridge Clay, up to the equivalent of the Freshwater Steps Stone Band, in a partly overgrown section (SY 765 813) in which there were steady dips of 10° to 20°. As well as this latter stone band, the equivalents of the White and ?Grey Ledge stone bands formed prominent features, and a thick oil shale with calcareous concretions appeared to be the equivalent of the Blackstone. The latter was mainly deeply weathered, and the tiny pyritized plates of the pelagic crinoid *Saccocoma*, which in the type sections (see site report for Tyneham Cap–Hounstout, this volume) characterize this bed, were not recorded. At the east end of the bay, the high cliff west of Holworth House is still known as 'Burning Cliff' after spontaneous combustion of a bituminous shale (almost certainly the equivalent of the Blackstone) which took place in 1826 and continued for several years (Buckland and De la Beche, 1836; Arkell, 1933, 1947a). The Holworth House Fault, with a downthrow to the east of about 45 m, affects the succession at this eastern end of the bay. The highest beds of the Kimmeridge Clay, down to the level of the White Stone Band, are intermittently exposed beneath the Portland Group on its downthrown side (Arkell, 1947a; Cope, 1980; House, 1989).

Interpretation

The marker beds recognized in the Kimmeridgian succession at Ringstead Bay enable correlation with other sections in the Dorset type area (Figure 2.14) and further afield. These include, from below, the Inconstans Bed, Nana Bed, Wyke Siltstone, Black Head Siltstone, ?Hobarrow Bay Stone Band, Nannocardioceras Cementstone, ?Cattle Ledge Stone Band, ?Grey Ledge Stone Band, ?Blackstone, White Stone Band, ?Middle White Stone Band and Freshwater Steps Stone Band (Figures 2.15 and 2.23). Together with the recorded ammonite faunas, these substantiate an almost complete Kimmeridgian zonal sequence; the Fittoni Zone has not been proved definitely at the top of the succession but Cope (1980) considered that it was almost certainly present. Although, historically, a section at Ringstead Bay has been considered as the stratotype for the base of the Kimmeridgian Stage, recent deliberations by the Kimmeridgian Boundary Working Group of the International Subcommission on Jurassic Stratigraphy (ISJS) tended to favour a section a little further west at Black Head (see site report for Black Head, this volume) as British candidate for the Global Stratotype Section and Point (GSSP) (Atrops, 1997).

As elsewhere on the Dorset coast, Brookfield's (1978) suggestion, following Blake (1875), that the boundary beds between the Kimmeridge Clay and underlying Corallian Group should be differentiated as a separate 'Passage Beds Formation' has not found acceptance (see site report for East Fleet–Small Mouth, this volume, for discussion).

Conclusions

Although exposure is patchy and variable, an almost complete Kimmeridge Clay succession has been recorded in the landslipped cliffs at Ringstead Bay and there are a number of marker beds that enable correlation with other Kimmeridgian sections on the Dorset coast and further afield. The locality is best known for the exposures of the basal beds of the formation and the underlying Corallian Group that have provided a long-standing candidate GSSP for the base of the Kimmeridgian Stage. Although affected by modern coastal protection work, the boundary crops out in the low, grassy cliffs to the west and east of the slipway at Ringstead village. The base of the Kimmeridgian is marked by the base of the Inconstans Bed, named after the brachiopod *Torquirhynchia inconstans* (J. Sowerby) and including the ammonite *Pictonia densicostata* Salfeld (Arkell, 1947a, pl. 4, fig. 1). The locality gives its name to the Late Oxfordian ammonite genus *Ringsteadia* (Salfeld, 1913) and is the type locality of the Ringstead Coral

Bed, the youngest bed of the Oxfordian, which represents a local facies development within the Osmington Mills Ironstone Member. The locality had a long association with W.J. Arkell (1904–1958) who spent most of his vacations in the chalet called 'Faraways' where he wrote much of the classic memoir on this area for the Geological Survey (Arkell, 1947a). Ringstead Bay is thus a key site, of national and international importance, for stratigraphy and stratigraphical palaeontology, as well as having close associations with one of the greatest world authorities on the Jurassic System.

SANDSFOOT (SY 687 788–SY 671 770)

J.K. Wright

Introduction

The significance of the exposures of Corallian strata in the Sandsfoot GCR site first became apparent in the early 19th century when the locality was described briefly by Sedgwick (1826), and later by Fitton (1827). A fuller account was provided by Buckland and De la Beche (1836, pp. 23–7). Blake and Hudleston (1877), Hudleston (1889) and Woodward (1895) provided the best of the 19th-century descriptions of the site. Arkell's more detailed description of the sections (Arkell, 1936a, 1947a) best emphasizes the important role played by this site in studies of Oxfordian geology. Subsequently, the locality has figured prominently in several specialist studies concerning Oxfordian stratigraphy, sedimentology, palaeogeography and taxonomy (Morris, 1968; Wilson, 1968a; Brookfield, 1973a, 1978; Talbot, 1973a, 1974; Fürsich, 1975, 1977; Wright, 1986a, 1998).

Description

This shallowly dipping Corallian sequence lies on the southern side of the Weymouth Anticline. It comprises rock platform and low cliff exposures extending from Nothe Point to Sandsfoot Castle (Figure 2.16). The sequence is much less well exposed than formerly. Due to landscaping, building works and defences against cliff erosion, plus the inhibition of marine erosion caused by the construction of the Portland Harbour breakwater, there are now only inter-

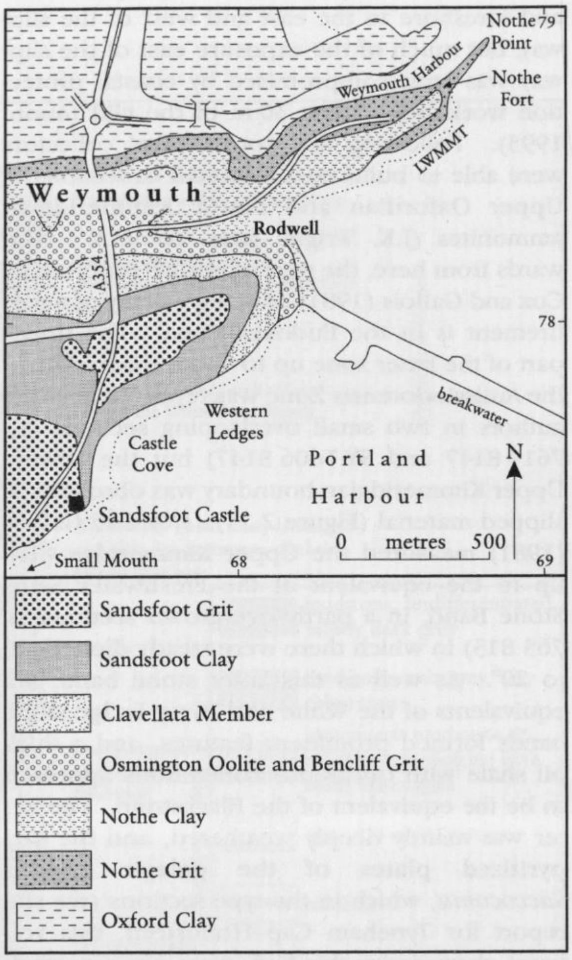

Figure 2.16 Sketch map of the solid geology in the vicinity of the Sandsfoot GCR site.

mittent exposures. The potential maximum thickness is 84 m. The sequence spans all seven Corallian ammonite zones and comprises 13 stratigraphical units, five of which, the Nothe Grit, Nothe Clay, Bencliff (Bincleaves) Grit, Sandsfoot Clay and Sandsfoot Grit, have their type localities along this stretch of coastline. Figure 2.17 lists all the members and formations present. The zonal ranges of these are as shown in Figure 2.7. The section was regarded by the early authors (e.g. Buckland and De la Beche, 1836) as the type locality for the Corallian Group in south Dorset. A definitive version of the stratigraphy was given by Wright (1986a). A weathering profile of the lower part of the succession is given in Figure 2.18, and a weathering profile of the Sandsfoot Grit is given in Figure 2.20. The revised subdivision follows Wright (in

Substage	Formation	Member			Thickness (metres)
Upper Oxfordian	Sandsfoot	Osmington Mills Ironstone		*	0.3
		Ringstead Clay		*	5.0
		Sandsfoot Grit			11.3
	Clavellata	Sandsfoot Clay		*	15.5
		Clavellata	Red Beds†	*	1.5
			Clay Band†	*	1.0
			Chief Shell Beds†		2.02
			Sandy Block†		1.57
Middle Oxfordian	Osmington Oolite	Nodular Rubble			1.8+
		Shortlake		*	6.1+
		Upton		*	4.5+
	Redcliff	Bencliff Grit		*	4.0
		Nothe Clay			13.5
		Preston Grit			1.8
Lower Oxfordian		Nothe Grit			9.0

* largely not exposed or inaccessible at present
† informal subdivision – see text

Figure 2.17 The complete stratal succession at the Sandsfoot GCR site.

press) (see site report for Osmington, this volume). Details of the succession are as follows.

Redcliff Formation (27.5 m+)

Blake and Hudleston (1877) named the Nothe Grit Member after the '30 ft (9 m) of calcareous sandstone with hard bands of grit well exposed beneath the Nothe Fort at the end of Weymouth Pier' (SY 687 788). At low tide the upper 5 m of the Nothe Grit is still visible. It consists of argillaceous, very fine-grained sandstone with the frequent development of calcareous concretions (beds 1, 4, Figure 2.18), much more so than at Red Cliff (see site report for Osmington GCR site report, this volume). A substantial bivalve and ammonite fauna is present in a bed of calcareous sandstone near the base of the succession (Wright, 1986a).

At the southern end of Nothe Point (SY 685 786), 1.8 m of the Preston Grit Member is exposed in the wave-cut platform (Figure 2.19). It comprises a massive, fine- to medium-grained, shelly sandstone with excellent infilled *Thalassinoides* burrow networks (Bed 8, Figure 2.18). The highest 0.45 m seen (Bed 9) consists of medium-grained, sandy limestone with a layer of *Myophorella hudlestoni* (Lycett) on the top surface (Wright, 1986a). The junction with the overlying Nothe Clay is not exposed.

At the type locality at Rodwell (SY 684 785), the lower 8 m of the Nothe Clay Member is intermittently exposed as a gently dipping succession in the rock platform. Almost 50% of the succession is limestone, there being eight distinct limestone beds, numbered NCL1 to NCL8 in Figure 2.18, ranging in composition from shelly micrite to oomicrite, separated by layers

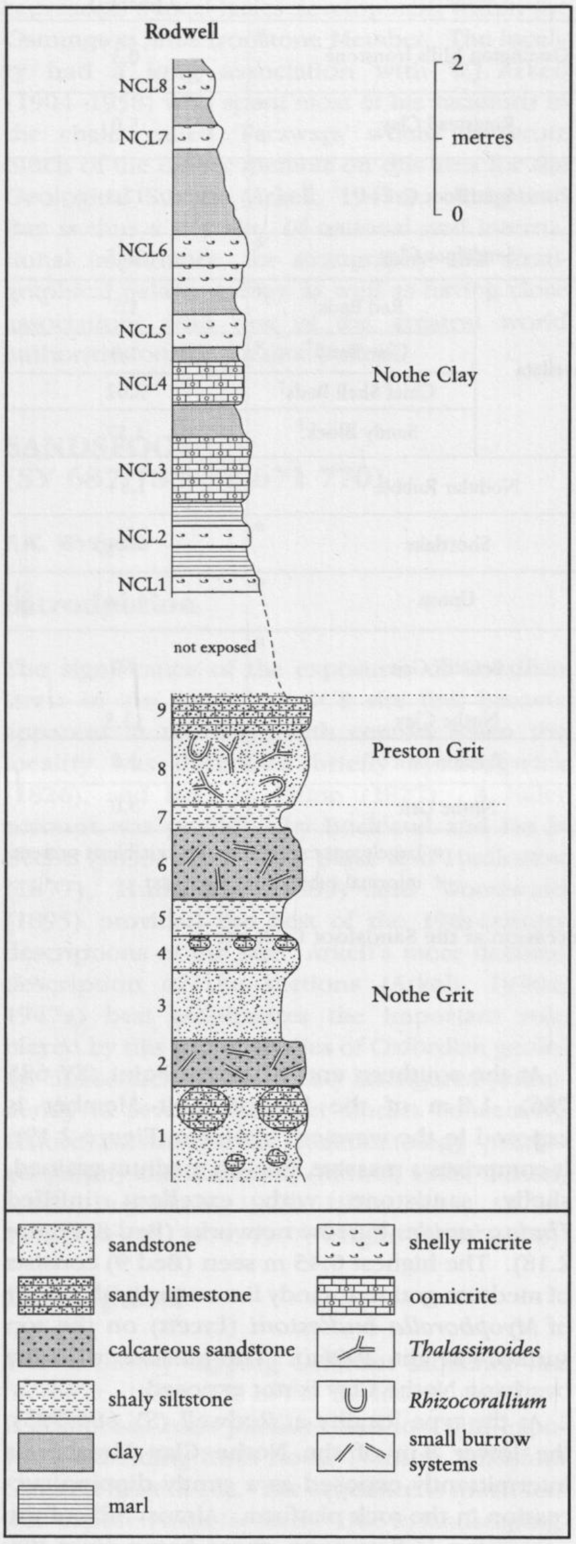

Figure 2.18 Weathering profile of the Redcliff Formation between Nothe and Rodwell (after Wright, 1986a, figs 2 and 3).

of clay. Bored, encrusted limestone pebbles are common towards the top of the succession. The recent installation of sea defences means that the upper 5.5 m of this sequence (beds NCL5 to NCL8, Figure 2.18) is much less well exposed than formerly.

The Bencliff Grit Member is no longer exposed. Blake and Hudleston (1877) saw 'sandy shales and loose, foxy sands which contain towards the base huge tabular doggers of indurated, calcareous sandstone' (3.3 m).

Osmington Oolite Formation (12.5 m+)

There are excellent cliff exposures of this formation, but they are largely on land owned by the Defence Research Agency, and are not accessible to the public. Blake and Hudleston (1877) described the section. Following Arkell (1936a), beds that they included in the Bencliff Grit below and the Clavellata Formation above are now included within an enlarged Osmington Oolite Formation. The following can be pieced together from Blake and Hudleston's account (Blake and Hudleston's bed numbers in brackets; metric thicknesses have been substituted):

		Thickness (m)
Nodular Rubble Member		
7.	Irregular, blue-weathering, impure limestone in hummocky masses	1.83
Shortlake Member		
6. (1)	Blue, marly clay with oolitic grains	1.98
5. (2)	Small-grained, sandy oolite, weathering hummocky by having a bioclastic limestone substituted towards the base	0.60
4. (3)	Marly clay with doggers	1.68
3. (4)	Oolite, gritty in the centre and marly below, with *Aspidoceras perarmatum* (J. Sowerby)	1.82
Upton Member		
2. (5)	Blue, sandy marl, partly argillaceous	1.21
1.	Calcareous grit with dichotomizing branches, very hard in the upper part, passing down into soft, calcareous sands with a band of compact, argillaceous limestone at the base	3.35

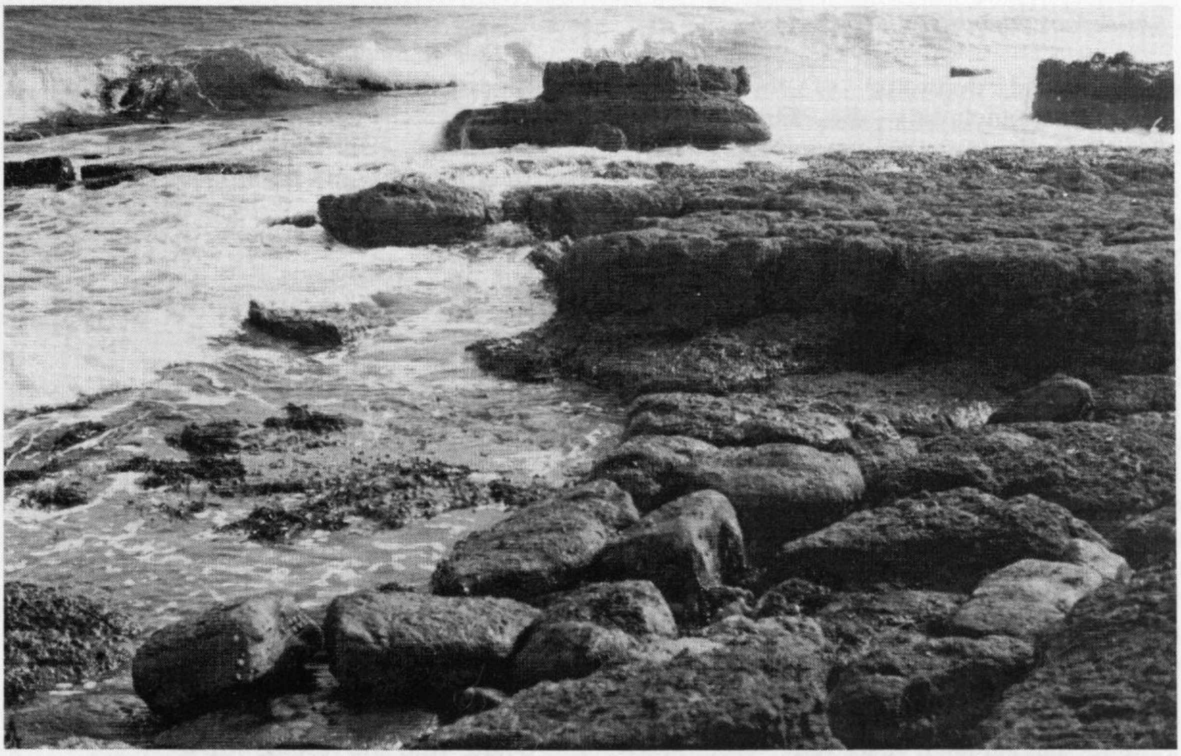

Figure 2.19 Preston Grit exposed in the rock platform just east of Nothe Fort. (Photo: J.K. Wright.)

It is not possible to ascertain whether there are any gaps in this succession. Bed 1 was notably fossiliferous, with several species of bivalve and gastropod, including *Cucullaea contracta* Phillips, *Chlamys qualicosta* (Étallon), *Trigonia* sp. and *Cerithium* sp.. Blake and Hudleston comment that the Shortlake Member is markedly more argillaceous here than elsewhere in south Dorset. The distinctive Nodular Rubble Member is accessible in Castle Cove (see below).

Clavellata Formation (20 m+)

South of the Defence Research Agency land, there are substantial exposures of the Clavellata Member in the Western Ledges and low cliffs of Castle Cove (Figure 2.16). This is the type section of the member as defined by Blake and Hudleston (1877). The Sandy Block and Chief Shell Beds are best seen in the base of the cliff as the reefs in the centre of the cove are covered with an almost impenetrable mass of seaweed, and more recently occupied by a large pier constructed on stilts.

At (SY 680 778), a fossil wave-cut platform in the Nodular Rubble Member of the Osmington Oolite Formation is excellently displayed, with laminated sands of the Sandy Block wrapping round bored limestone hummocks. Above the non-sequence are 0.15 m of sandy clay, and the Sandy Block succession is completed by two tiers of limestone totalling 1.42 m. Scattered *Myophorella clavellata* (Parkinson) occur in life position.

Exposures of the Chief Shell Beds (2.02 m) at (SY 677 777) consist of argillaceous, fossiliferous, oolitic limestone. Higher parts of the Clavellata Member succession are not seen at present.

The Sandsfoot Clay Member type section of Blake and Hudleston (1877) was at Castle Cove. The area is now largely vegetated and built over, and there is little beach exposure. Woodward (1895) described 11.7 m of blue, fossiliferous clay. Wright (1986a, 1998) considered that the true thickness was 15.5 m. Under favourable beach conditions the top 0.5 m of Sandsfoot Clay, consisting of very fine-grained mudstone, can be seen beneath the Sandsfoot Grit at (SY 676 775).

Sandsfoot Formation (16.8 m+)

The revised definition of the Sandsfoot Formation, including the Sandsfoot Grit, Ringstead Clay and Osmington Mills Ironstone members, follows Wright (in press).

The first accurate measured section of the Sandsfoot Grit Member as exposed in the cliff sections beneath Sandsfoot Castle (SY 676 775–SY 672 771) was provided by Wright (1986a) as follows (Figure 2.20):

	Thickness (m)
Unit V	
9. Tough, iron-rich, fine- to medium-grained sandstone with a red, iron-stained top surface. Scattered chamosite ooids are present. The bed is heavily bioturbated by *Thalassinoides*, and contains *Goniomya* sp. and *Liostrea* sp.	0.45
8. Massive, brown-weathering, fine- to medium-grained chamositic sandstone, very soft and argillaceous	1.38
7. Grey, fine- to medium-grained, calcareous sandstone, heavily bioturbated with the burrow infillings weathering out. Fragmentary *Chlamys midas* (Damon) are common, with *Liostrea* sp. and *Pleuromya* sp.	0.61
Unit IV	
6. Yellow-weathering, light grey, slightly sandy clay	approx. 1.20
Unit III	
5. Argillaceous, iron-rich, largely fine-grained chamositic sandstone. Distinctive patches of light grey micrite are present, containing well-preserved chamosite ooids. *Ringsteadia* spp. and *Microbiplices anglicus* Arkell weather out	1.90
4. Tough, prominent, sideritic pebbly sandstone with a fine-grained or fine- to medium-grained matrix. Bioturbation is strong, but the considerable fauna is well preserved: *Ringsteadia* sp., *Pinna sandsfootensis* Arkell, *Chlamys midas, Ctenostreon* sp., *Deltoideum delta* Smith, *Isognomon* sp. and *Goniomya* sp.	0.55
3. Tough, well-bedded, fine-grained or fine- to medium-grained sandstone, iron-rich, with poorly preserved chamosite ooids. Not particularly fossiliferous, with *Pinna sandsfootensis* and *Trichites* sp.	1.80
Unit II	
2. Soft, very argillaceous, fine- to medium-grained sand with clay partings. *Deltoideum delta* is abundant, and the unit is coarse and shelly at the base	approx. 2.30
Unit I	
1. Well-bedded, glauconitic sandy limestone or calcareous sandstone. *Perisphinctes (P.)* aff. *strumatus* (Buckman) occurs, along with numerous *Pleuromya uniformis* (J. Sowerby). The base consists of a coquina of belemnite guards, oyster fragments, etc., set in a medium quartz sand and resting with a sharp junction on Sandsfoot Clay	1.13

A weathering profile of the section is given in Figure 2.20. Unit I contains 40% calcium carbonate and is almost a limestone. Unit II was confused with the Sandsfoot Clay by the early workers. However, it contains 50% fine quartz sand and 10% medium, and is an argillaceous sand. The clastic content of beds 3 and 4 is not markedly greater than that of Bed 2, and it is the incoming of iron – originally as iron silicate, now disseminated as siderite – that has cemented the rock (Figure 2.21). Bed 4 is markedly pebbly, with 10 mm pebbles of dark quartzite. Unit IV is unique in the Sandsfoot section – a pale grey, almost insoluble clay. Unit V marks a return to the deposition of sandy ironstone, coarser than the beds in Unit III. Units I to IV are exposed in the cliffs below Sandsfoot Castle. Unit V is seen only in the low cliffs at the south end of the small bay south of the Sandsfoot cliffs, where it rests on the clay of Unit IV.

There is no natural exposure of the uppermost Oxfordian Ringstead Clay Member and Osmington Mills Ironstone Member in the Sandsfoot GCR site due to the construction of a yacht storage area and small piers on the outcrop. A temporary section exposed in 1998 during construction of a car park for the 'Scuba Shack' (SY 672 772) revealed the junction of

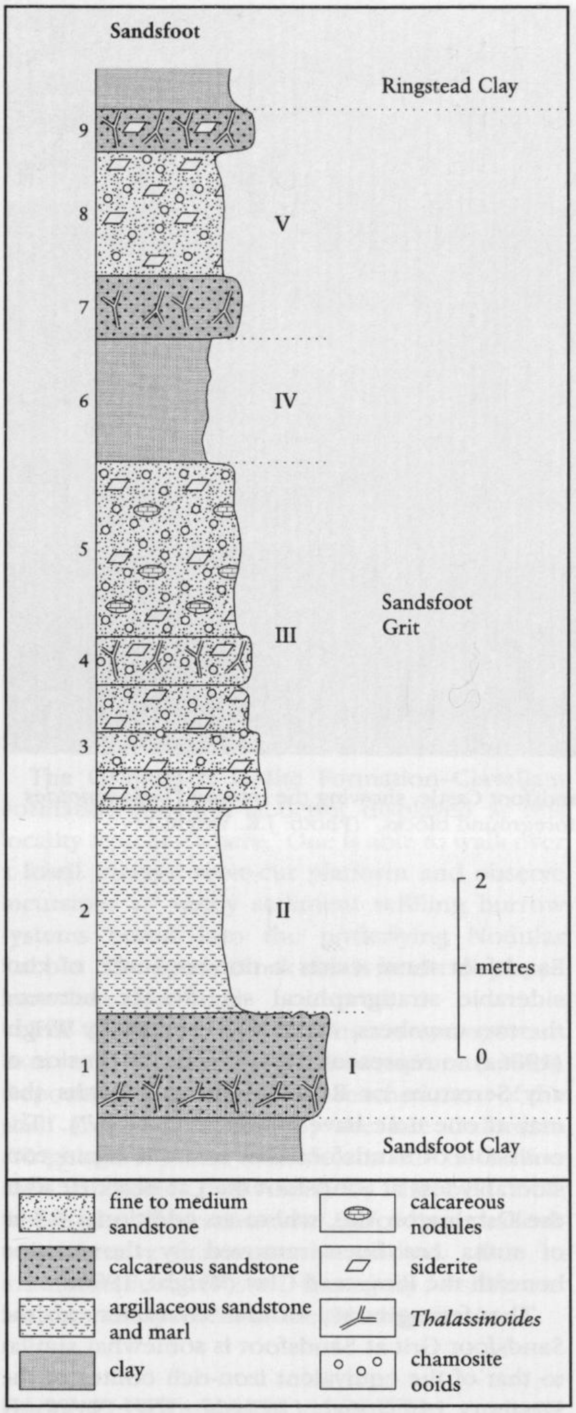

Figure 2.20 Weathering profile of the Sandsfoot Grit in the cliff section beneath Sandsfoot Castle (after Wright, 1986a, fig. 5).

mudstone with brown siderite nodules (Ringstead Clay) overlain by shelly, iron-oolite marl (Osmington Mills Ironstone).

Interpretation

Comparison of the Sandsfoot succession with that seen at Osmington (see site report for Osmington, this volume) reveals significant differences. These are caused either by changes in facies, or by non-sequences at Osmington being much less markedly developed at Sandsfoot, giving a more complete succession.

The sands of the Nothe Grit Member are fine grained and bioturbated. Fine, offshore, silty sands pass up into well-sorted, subtidal sands laid down quite close to the beach environment.

Sedimentation in the Preston Grit Member took place after a break and minor uplift. Small pebbles of fine-grained sandy limestone imply erosion of Nothe Grit nearby. The Preston Grit is much coarser in grain size at Nothe than at Redcliff, implying a shallower-water, near-beach environment in this southerly direction (Wright, 1986a), with the uppermost 0.45 m being a true sandy, shelly, bioclastic limestone.

The Nothe Clay is a comparatively shallow-water clay unit, not fully open marine. Ammonites are very infrequent in the clay facies, and there are only occasional burrowing bivalves. Shell sand was able to transgress repeatedly, presumably coming from the south-west, as these limestone beds are thicker here than at Red Cliff (see Osmington GCR site report, this volume). Each of the shelly bands marks the building out of high-energy shell sand into a comparatively shallow clay-depositing sea. The Nothe Clay at Rodwell thus contains a varied sequence of limestone beds with frequent pebbles and erosive features demonstrating the close proximity of shallow-water conditions during deposition of this unit, and again indicating a southerly shallowing, in contrast to the deeper-water sequence at Redcliff. The Bencliff Grit is remarkably similar in facies to that seen at Bran Point (see site report for Osmington, this volume), indicating that the special conditions that gave rise to its formation must have been widespread.

The basal Upton Member, a sandy limestone at Osmington, is so sandy at Sandsfoot that Blake and Hudleston called it a calcareous grit, and grouped it with the Bencliff Grit. Though the Shortlake Member is argillaceous here, this is not an indication of deepening, for the member is present as strongly cross-bedded oolite in the Rodwell Railway Cutting 1 km to the west (Blake and Hudleston, 1877). The Nodular Rubble

Figure 2.21 Massive Sandsfoot Grit of Unit III below Sandsfoot Castle, showing the intense ***Thalassinoides*** bioturbation of the harder bands weathering out in the foreground blocks. (Photo: J.K. Wright.)

Member shows again the irregularly weathering bedding planes produced by diagenesis of *Thalassinoides* burrows.

Prior to the accumulation of the Clavellata Formation, a marine bench was cut into the Nodular Rubble and colonized by numerous burrowing organisms. As the basin subsided, allowing sediment to accumulate, marginal areas appear to have been uplifted, resulting in the fine quartz sand of the Sandy Block being swept into the basin. Clastic input was slight during deposition of the Chief Shell Beds and Red Beds. Wilson (1968a, b) and Talbot (1973a, 1974) point to the presence of clay and micrite as indicating accumulation in water of moderate shelf depth away from strong wave action except during storms.

Both the Sandsfoot Grit and the Sandsfoot Clay demonstrate considerable thickness increases when compared with the equivalent strata at the Osmington site (Wright, 1986a). The Sandsfoot Clay increases from 3.9 m to an estimated 15.5 m, due to much lesser erosion beneath the Sandsfoot Grit. However, even at Sandsfoot there exists a non-sequence of considerable stratigraphical significance between the two members, which was thought by Wright (1986a) to represent the omission by erosion of any Serratum or Regulare Zone deposits that may at one time have existed (Figure 2.7). The omission of Sandsfoot Grit strata is again considerably less at Sandsfoot than at Black Head in the Osmington site, where an additional 4.3 m of strata has been removed by the erosion beneath the Ringstead Clay (Wright, 1986a).

The ferruginous, ooidal character of the Sandsfoot Grit at Sandsfoot is somewhat similar to that of the equivalent iron-rich oolites of the Westbury Ironstone of Wiltshire (see Westbury GCR site report, this volume), and also the early Kimmeridgian Abbotsbury Ironstone (see site report for Blind Lane, this volume). The coarse grained nature of much of the sediment implies deposition under shallow, high-energy conditions. Changes in thickness of individual units in the section at East Fleet compared with those at Sandsfoot are marked (Wright, 1998). The Sandsfoot Grit represents a barrier sand whose formation was triggered by the uplift that led to the erosion of the Sandsfoot Clay. The more argillaceous units II and IV accumulated in shallow, brackish or possibly hypersaline lagoonal areas. Bed 4 has yielded a substantial bivalve fauna, and was made the type of the *Pinna* association by Fürsich (1977). This fauna of shallow-burrowing and surface-dwelling bivalves lived in or on the sandy sediment where it is found, specimens of *Pinna* frequently being found in life position or slightly disturbed but with the valves still together. Intraformational erosion has removed most of these very fossiliferous beds from the Osmington site (Wright, 1986a).

Conclusions

This is a key site in Jurassic studies. It includes the type localities of the Nothe Grit, Nothe Clay, Sandsfoot Clay (unfortunately obscured) and Sandsfoot Grit. There is a good exposure of the Preston Grit in its *Myophorella hudlestoni* shell-bed facies, exemplifying the alternative name for this unit of 'Trigonia hudlestoni Bed'.

The Osmington Oolite Formation–Clavellata Formation junction is better displayed at this locality than elsewhere. One is able to walk over a fossil Jurassic wave-cut platform and observe incursions of sandy sediment infilling burrow systems bored into the underlying Nodular Rubble. The Sandy Block also is better displayed here than elsewhere.

The Sandsfoot Grit contains a very important fauna of late Oxfordian bivalves and ammonites. Deposition of clay facies had reached most of the shelf areas of England by the late Oxfordian (Wright, 1980), and Sandsfoot is one of the few areas in Britain, and certainly the best area, where the distinctive late Oxfordian shallow-water bivalve fauna can be studied. Due to intraformational erosion, these very fossiliferous beds are not present at the Osmington site.

EAST FLEET–SMALL MOUTH (SY 659 767–SY 667 763 AND SY 669 765–SY 672 772)

B.M. Cox

Introduction

The foreshore and low, slipped and weathered cliffs at the eastern end of The Fleet at Wyke Regis (SY 659 767–SY 667 763) and south of Sandsfoot Castle (SY 669 765–SY 672 772) (for locations see Figures 2.12, 2.22), expose the Baylei and Cymodoce zones of the basal Kimmeridgian, together with the underlying Oxfordian. The sections at both localities are now degraded because they are protected from marine erosion by, respectively, Chesil Beach and Portland Harbour breakwater. Nevertheless, they have featured in the literature for over a century, and continue to yield fossils from the Oxfordian–Kimmeridgian boundary beds. The boundary succession is thicker here than at other localities on the Dorset coast (Cox and Sumbler, 1994).

Description

The sections have been reported by Sedgwick (1826), Buckland and De la Beche (1836), Damon (1860), Waagen (1865), Blake (1875), Blake and Hudleston (1877), Woodward (1895), Strahan (1898), Salfeld (1914), Arkell (1933, 1936, 1947a), Morris (1968), Birkelund *et al.* (1978), Brookfield (1978), Cox and Gallois (1981) and House (1989). The early authors concentrated on the section near Sandsfoot Castle, which, in the 19th century, was the best available exposure of basal Kimmeridgian strata, such that Waagen (1865) used it for the first definition of the base of the Kimmeridge Clay. South of Sandsfoot Castle, towards Ferry (or Small Mouth) Bridge, the basal beds of the latter formation, up to *c.* 15 m thick but often badly slipped, were formerly exposed above the Osmington Mills Ironstone and Ringstead Clay members of the Upper Oxfordian (Figure 2.23) but recent building works have compromised the exposure (J.K. Wright, pers. comm.). The Oxfordian beds at this locality are included in the Oxfordian GCR Block (see site report for Sandsfoot, this volume). Later authors seem to have found the slightly shorter section at the eastern end of The Fleet more favourable. There, the low cliffs north-west of Ferry Bridge, and the foreshore beyond the first promontory, expose beds from the Ringstead Clay through to the lowest beds of the Kimmeridge Clay. The beds, which dip gently and steadily to the south, are badly slumped and must be exposed by digging, but the same stratigraphical and faunal succession as at Sandsfoot follows simply from the relative position of the beds on the beach. The

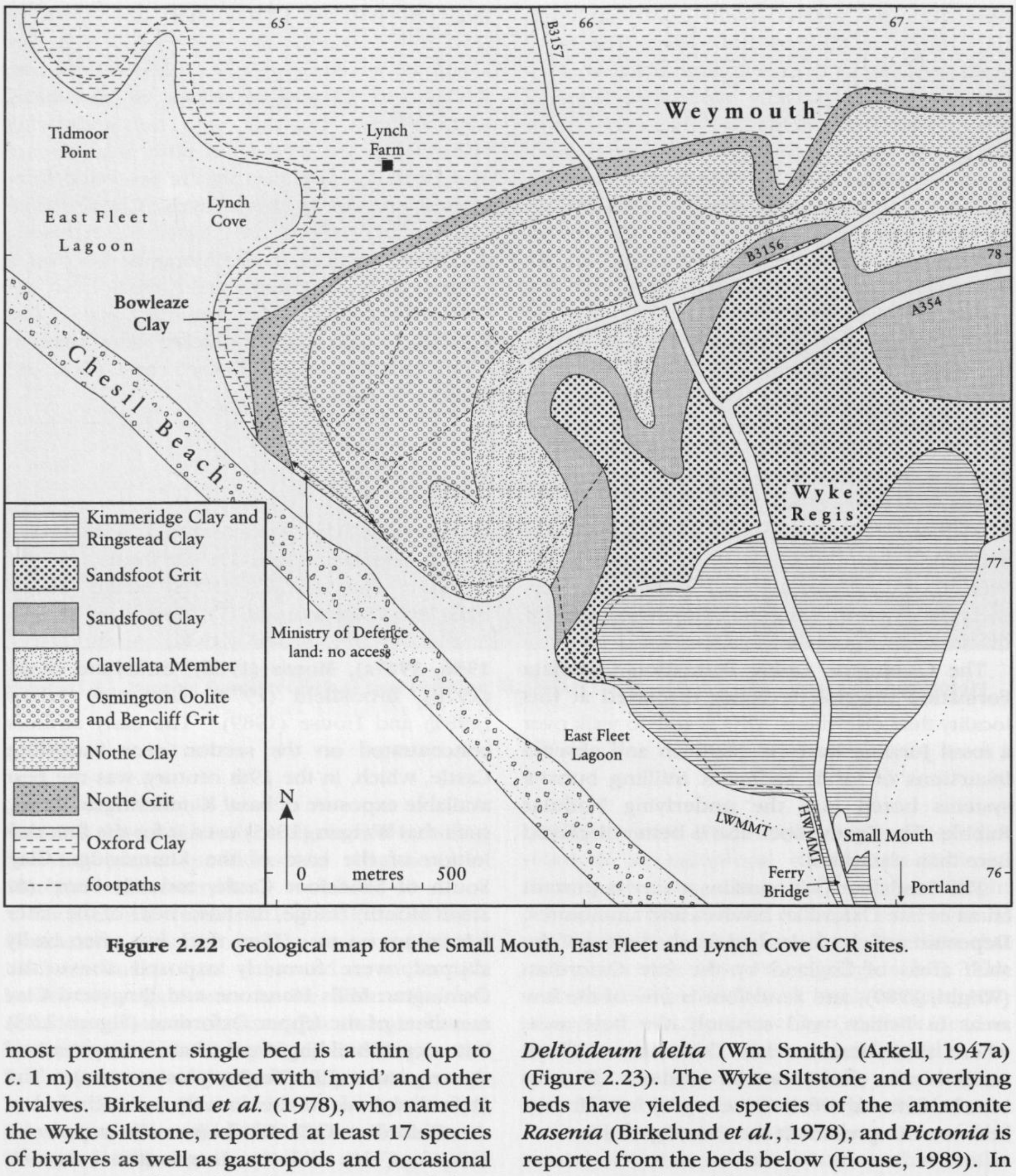

Figure 2.22 Geological map for the Small Mouth, East Fleet and Lynch Cove GCR sites.

most prominent single bed is a thin (up to *c.* 1 m) siltstone crowded with 'myid' and other bivalves. Birkelund *et al.* (1978), who named it the Wyke Siltstone, reported at least 17 species of bivalves as well as gastropods and occasional ammonites. The bed is also seen at Sandsfoot. At both localities, a bed of similar lithology, in an otherwise mudstone succession, occurs 1–2 m above the Wyke Siltstone, and was named the Black Head Siltstone by Cox and Gallois (1981). Lower down in the succession, the Nana Bed, rich in the small oyster *Nanogyra nana* (J. Sowerby), and the Inconstans Bed, with the eponymous brachiopod *Torquirhynchia inconstans* (J. Sowerby), have also been recorded together with clays rich in the flat oyster *Deltoideum delta* (Wm Smith) (Arkell, 1947a) (Figure 2.23). The Wyke Siltstone and overlying beds have yielded species of the ammonite *Rasenia* (Birkelund *et al.*, 1978), and *Pictonia* is reported from the beds below (House, 1989). In addition, the low cliffs to the east of Ferry Bridge have yielded many marine reptile remains (e.g. Delair, 1986) and this part of the site is included in the GCR volume on British fossil reptiles (Benton and Spencer, 1995). At both localities, the youngest Oxfordian stratum (the Osmington Mills Ironstone but, in the past, often referred to as the 'Ringstead Coral Bed') is a pale ironshot oolite full of fossils, notably serpulids and the coarsely corrugated bivalve *Ctenostreon*, but without corals.

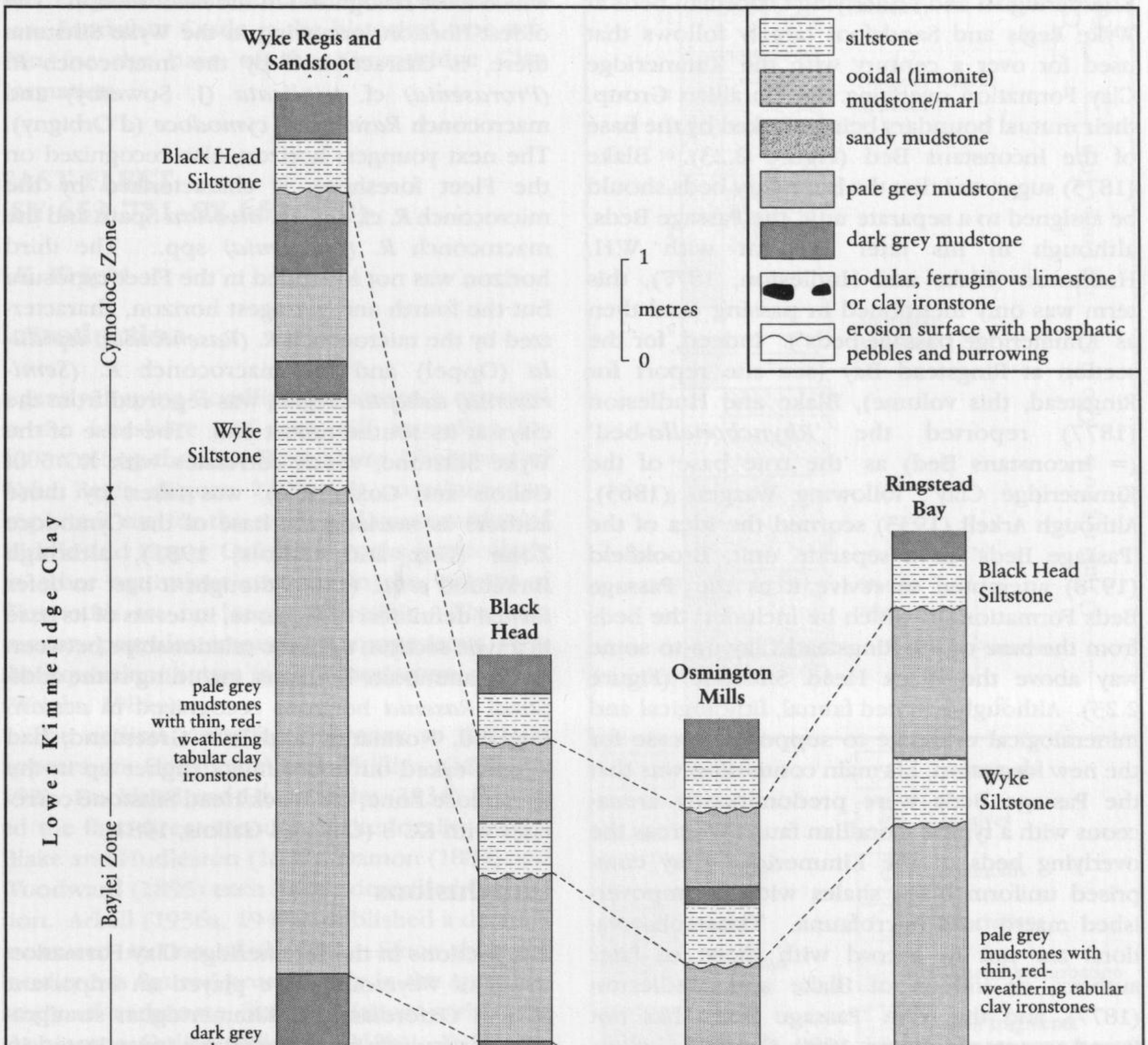

Figure 2.23 **Correlation of the basal beds of the Kimmeridge Clay exposed at Wyke Regis, Sandsfoot, Black Head, Osmington Mills and Ringstead Bay (based on Cox and Gallois, 1981, fig. 6 and unpublished borehole data, R.W Gallois, pers. comm.).**

Interpretation

The lithostratigraphical classification of the Kimmeridgian and underlying Oxfordian beds at Wyke Regis and Sandsfoot largely follows that used for over a century with the Kimmeridge Clay Formation overlying the Corallian Group, their mutual boundary being marked by the base of the Inconstans Bed (Figure 2.23). Blake (1875) suggested that the boundary beds should be assigned to a separate unit, the Passage Beds, although in his later account with W.H. Hudleston (Blake and Hudleston, 1877), this term was only mentioned in passing (and then as 'Kimmeridge passage-beds'). Indeed, for the section at Ringstead Bay (see site report for Ringstead, this volume), Blake and Hudleston (1877) reported the '*Rhynchonella*-bed' (= Inconstans Bed) as 'the true base of the Kimmeridge Clay', following Waagen (1865). Although Arkell (1933) scorned the idea of the 'Passage Beds' as a separate unit, Brookfield (1978) attempted to revive it as the 'Passage Beds Formation' in which he included the beds from the base of the Ringstead Clay up to some way above the Black Head Siltstone (Figure 2.23). Although he cited faunal, lithological and mineralogical evidence to support the case for the new formation, his main contention was that the Passage Beds were predominantly arenaceous with a typical Corallian fauna whereas the overlying beds of the Kimmeridge Clay comprised uniform black shales with an impoverished macro- and microfauna. These observations are not in accord with those of later authors, or indeed of Blake and Hudleston (1877), and the term 'Passage Beds' has not found acceptance (Cope, 1980; Cox and Gallois, 1981; Wright, 1986). The Ringstead Coral Bed, to which the youngest unit of the Oxfordian succession is often referred, is now recognized as only a local development (see site report for Ringstead, this volume) within a more widespread facies (the Osmington Mills Ironstone Member) comprising very variable limonite-oolite marl, which is occasionally well enough cemented to form an impure limestone (Brookfield, 1978; Wright, 1986).

The Fleet section was used by Birkelund *et al.* (1978) in their assessment of the ammonite genus *Rasenia* and the associated stratigraphy of the Lower Kimmeridgian Cymodoce Zone. Both *Pictonia*, characteristic genus of the underlying Baylei Zone, and *Rasenia* are in need of monographic treatment. Within the Cymodoce Zone, these authors recognized four horizons characterized by different *Rasenia* faunas, three of which were recognized in the Fleet section. The oldest horizon, occurring in the Wyke Siltstone there, is characterized by the microconch *R. (Prorasenia)* cf. *triplicata* (J. Sowerby) and macroconch *Rasenia* cf. *cymodoce* (d'Orbigny). The next youngest horizon, also recognized on the Fleet foreshore, is characterized by the microconch *R.* cf. and aff. *involuta* Spath and the macroconch *R. (Eurasenia)* spp.. The third horizon was not identified in the Fleet exposure but the fourth and youngest horizon, characterized by the microconch *R. (Rasenioides) lepidula* (Oppel) and the macroconch *R. (Semirasenia) askepta* Ziegler, was reported from the clays at its southernmost end. The base of the Wyke Siltstone, which correlates with KC 5 of Gallois and Cox (1976), was taken by those authors as marking the base of the Cymodoce Zone (Cox and Gallois, 1981), although Birkelund *et al.* (1983) thought it best to defer formal definition of the zone, in terms of its base in a type section, until the relationships between all the ammonite horizons, including some additional *Rasenia* horizons recognized in eastern England, Normandy and East Greenland, had been worked out more fully. Higher up in the Cymodoce Zone, the Black Head Siltstone correlates with KC 8 (Cox and Gallois, 1981).

Conclusions

The sections in the Kimmeridge Clay Formation south of Weymouth have played an important role in Oxfordian and Kimmeridgian stratigraphy, particularly since they were investigated in the 19th century when exposures in the low cliffs south of Sandsfoot Castle were particularly good. The exposures of Oxfordian strata here have been key sections for the lithostratigraphical units in the upper part of the Corallian Group but also for the basal beds of the Kimmeridge Clay above. Both here and at the eastern end of The Fleet, the Kimmeridgian beds are richly fossiliferous. They have yielded rich invertebrate faunas, including ammonites that have enabled a clearer understanding of the succession of *Rasenia* species in the Cymodoce Zone, as well as one of the most varied Kimmeridgian reptile faunas known; according to Benton and Spencer (1995), it is the best site for Kimmeridgian turtles and pterosaurs. The succession through the basal Kimmeridgian beds is thicker here than at other localities on the Dorset coast (see site report for Black Head and Ringstead, this volume), and the section near Sandsfoot Castle is the historical type section for the base of the Kimmeridge Clay Formation.

EAST FLEET (SY 653 771–SY 657 770)

J.K. Wright

Introduction

A gently dipping Corallian succession is exposed in the foreshore and low cliff extending for 600 m along the East Fleet shore 1 km west of Wyke Regis (Figure 2.22). It constitutes an important site for the study and conservation of Middle and Upper Oxfordian rocks, particularly as other equivalent sections in the vicinity of Weymouth are no longer accessible. The succession provides important comparisons with the equivalent strata in the Osmington section (Wright, 1986a).

The earliest recorded reference to this site appears in Conybeare and Phillips (1822, p. 192). Buckland and De la Beche (1836) provided the first direct account of the locality, whilst Blake and Hudleston (1877), Damon (1884) and Woodward (1895) each briefly described the section. Arkell (1936a, 1947a) published a detailed measured section of the site. Since then the locality has figured prominently in the specialist study of carbonate facies variation within the Osmington Oolite (Wilson, 1968b). Reference to the site has been made by Fürsich (1973, 1974, 1975, 1976a, b, 1977) and Brookfield (1973a, 1978), while Wright (1986a) has provided a detailed re-appraisal of this section, with a revised measured section.

Description

The East Fleet locality displays a 14 m Corallian succession spanning four stratigraphical units (see Figure 2.24). There is a well-exposed 12 m section through all three constituent members of the Osmington Oolite Formation, and the succession also includes the lowest two subdivisions of the Clavellata Formation, which overlies the Osmington Oolite non-sequentially (Wright, 1986a). The nomenclature, bed numbers and bed thicknesses below are taken from Wright (1986a). Due to mis-correlations by Arkell it was not possible to continue the use of Arkell's bed numbers (Arkell 1936a, 1947a).

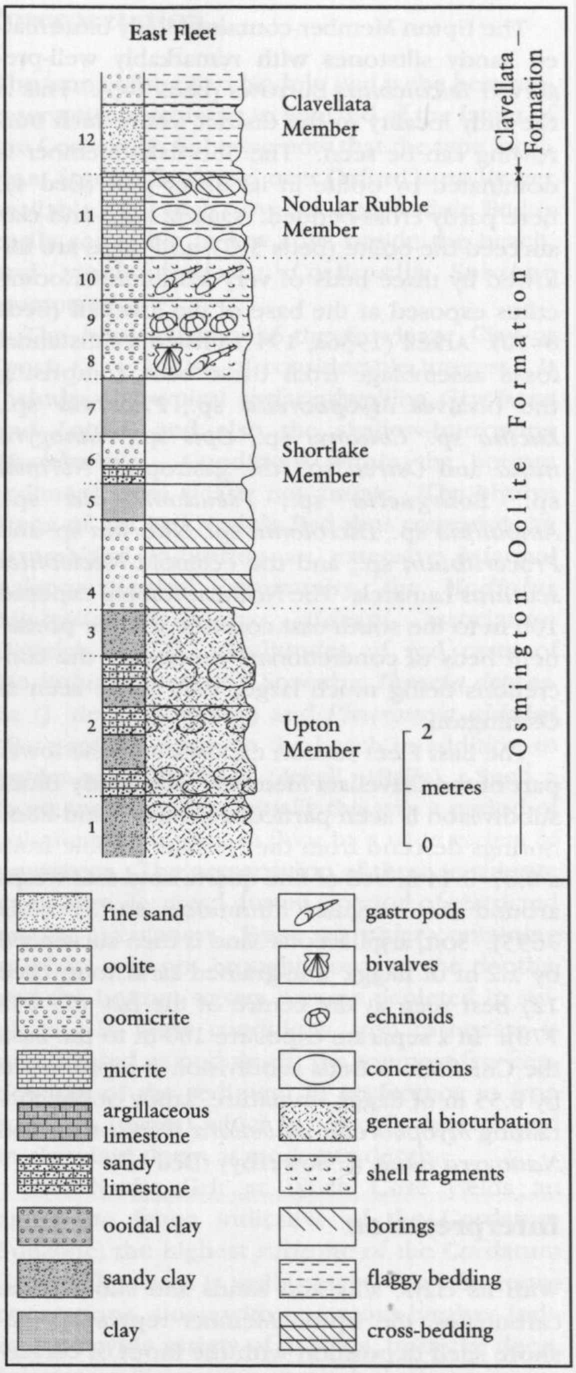

Figure 2.24 Log of the Corallian succession at East Fleet, after Wright (1986a, fig. 4). Note that Bed 7 is only 0.9 m thick – the thickness of 3.5 m given in Wright (1986a) is a misprint.

The Upton Member contains highly bioturbated sandy siltstones with remarkably well-preserved *Teichichnus* burrows (beds 1–3). This is the only locality in the district where such burrowing can be seen. The Shortlake Member is dominated by oolite in its lower part (Bed 4), here partly cross-bedded. Quartz sand and clay succeed the oolite (beds 5–7), and these are followed by three beds of very fossiliferous oomicrites exposed at the base of the low cliff (beds 8–10). Arkell (1936a, 1947a) listed a substantial fossil assemblage from these beds comprising the bivalves *Myophorella* sp., *Plicatula* sp., *Lucina* sp., *Chlamys* sp., *Opis* sp., *Nanogyra nana* and *Ostrea* sp., the gastropods *Nerinea* sp., *Bourguetia* sp., *Pseudomelania* sp., *Ampullina* sp., *Dicroloma* sp., *Littorina* sp. and *Procerithium* sp., and the echinoid *Nucleolites scutatus* Lamarck. The Nodular Rubble exposed 100 m to the south-east consists of three prominent beds of concretionary limestone, the concretions being much larger than those seen at Osmington.

The East Fleet section exposes only the lower part of the Clavellata Member. The Sandy Block subdivision is seen particularly well. Sand-filled borings descend from the Nodular Rubble from a 0.07–0.14 m bed of fine quartz sand that wraps around the irregular hummocks at (SY 6565 7695). Soft, argillaceous sand is then succeeded by 1.2 m of flaggy, fine-grained sandstone (Bed 12) best seen at the centre of the bay (SY 658 770). In a separate exposure 100 m to the east, the Chief Shells Beds subdivision is represented by 0.55 m of flaggy, immature, sandy oolite containing *Myophorella clavellata* (Parkinson) and *Nanogyra nana* (J. Sowerby) (Bed 13).

Interpretation

With its clays, silts and sands and subordinate carbonates, the Upton Member represents offshore shelf deposition with the input of considerable amounts of clastic sediment. The facies is more shallow water than that at Bran Point (see the Osmington GCR site report, this volume). There is then a marked break (Wright, 1986a, fig. 4), and the lower part of the Shortlake Member is thought to represent tidal ooid shoals and deltas, with marginal sponge-stabilized lagoonal intramicrites. The lagoonal content of the sequence increases upwards as beds of shelly micrite become common. The presence of these very fossiliferous beds is in marked contrast to Osmington, where the high-energy conditions with cross-bedded oolites precluded the preservation of any significant fauna.

The Nodular Rubble marks a return to deeper water, more settled conditions favouring the growth of the sponge *Rhaxella*. Wilson (1968b) and Fürsich (1973) each explained the nodular appearance of this limestone by intense bioturbation causing mixing of the sediments. However, there is a strong possibility that the effects of diagenesis have also played a role in the establishment of the nodular character.

The stratigraphical break that separates the Osmington Oolite Formation from the overlying Clavellata Formation almost certainly represents the omission of strata in the Nunningtonense Subzone (Wright, 1986a). There is very clear evidence for erosion of the Nodular Rubble at this site, the junction with the Clavellata Formation being more easily distinguished than at Black Head, as quartz sand rests on carbonates. As the Sandy Block passes up into the Chief Shell Beds, there is a reduction in quartz sand content, though the facies is still much more marginal than that at Osmington.

Conclusions

Study of the succession of sediments seen in the East Fleet site is essential to any full understanding of the sedimentology and palaeoenvironments of the Osmington Oolite Formation in southern Britain. The rich bivalve/gastropod fauna of beds 8–10 is of substantial interest, this being the only locality in south Dorset where such fossiliferous beds occur in the Osmington Oolite Formation. The clastic-dominated Upton Member and Clavellata Member demonstrate the passing of the fully marine sequence at Black Head (see site report for Osmington, this volume) into more marginal facies in the west.

LYNCH COVE (SY 648 780–SY 648 775)

J.K. Wright

Introduction

The low cliff and foreshore exposures on the southern shores of Lynch Cove, 400 m to 900 m south-west of Lynch Farm (SY 648 780–SY 648 775; Figure 2.22) include an important occurrence of the Red Nodule Bed. This is a horizon of sideritic nodules within the Costicardia Subzone of the Weymouth Member of the Oxford Clay. The section was first described by Blake and Hudleston (1877), and later by Woodward (1895). Arkell (1939b) listed ammonites collected from Lynch Cove. Later, Arkell monographed ammonites from the site (Arkell, 1935–1948), and provided the first full description (Arkell, 1947a).

Description

Southwards along the Fleet shore, there is present in the low cliffs a variably complete section through the Bowleaze Clay subdivision of the Weymouth Member of the Oxford Clay. The Bowleaze Clay is overlain by the Nothe Grit, which is capped by a thin representative of the Preston Grit. The beds dip very gently southwards, and this gentle dip, combined with frequent slumps obscuring the solid rock, precludes compilation of a measured section here.

Two metres of grey mudstone belonging to the Bowleaze Clay, and containing numerous *Gryphaea dilatata* J. Sowerby and *Lopha gregarea* (J. Sowerby) with occasional well-preserved *Myophorella hudlestoni* (Lycett), are exposed in the low cliff at (SY 647 777). The succession here is capped by the Red Nodule Bed, 0.3 m of clay containing two bands of red-weathering, sideritic nodules that infill or enclose *Cardioceras (Vertebriceras)* sp., *C. (Cardioceras)* aff. *costicardia* Buckman, '*Cerithium*' sp. and *Modiolus* sp.. The nodules weather out to form a readily recognizable rusty-coloured platform on the intertidal flat.

The junction with the overlying Nothe Grit is not seen. However, further southwards, the Nothe Grit is well exposed. It comprises a heavily bioturbated, very fine-grained sandstone with frequent calcareous concretions. The fauna is abundant, with numerous *Liostrea* sp. and *Nanogyra nana* (J. Sowerby), and also *Pleuromya* sp., *Myophorella hudlestoni*, *Cardioceras (Cardioceras) ashtonense* Arkell and *Goliathiceras* sp..

At the southern end of the exposure, close to the land owned by the Ministry of Defence, 0.45 m of Preston Grit is present overlying the Nothe Grit. It consists of a fine- to medium-grained, shelly sandstone with occasional *C. (Vertebriceras)* sp..

Interpretation

The fauna of the Red Nodule Bed is the best representative remaining in England of the fauna of the Costicardia Subzone now that the type locality at Studley Brickyard near Oxford is no longer available. At Lynch Cove the Red Nodule Bed is easily accessible in low cliffs beside the beach, and yields frequent Costicardia Subzone ammonites.

The bivalve fauna of the Bowleaze Clay at Lynch Cove is also of considerable interest. It includes the typical surface-dwelling *Gryphaea* and *Lopha*, and also the shallow-burrowing *Myophorella*. Conditions within the bottom sediment were clearly not anoxic. The bivalve fauna of the Red Nodule Bed thus comprises an assemblage indicating an extensive infaunal palaeoecological community, the *Modiolus bipartitus–Pleuromya alduini* association (Fürsich, 1977). Multitudes of red casts of *Modiolus bipartitus* J. Sowerby, *Thracia depressa* (J. de C. Sowerby) and *Pleuromya alduini* (Brongniart) occur on the beach in addition to *Lopha* and *Gryphaea* (Arkell, 1947a). Such a fauna indicates that initially this was a period of colonization of the sea floor by a wide variety of organisms. The preservation of these in siderite must have occurred during a period of restricted marine circulation. Fresh sea water containing sulphate was not brought down to the depths, and the bottom waters became depleted in sulphate. In these conditions, iron carbonate is precipitated as nodules in the topmost few centimetres of the sediment in preference to iron sulphide (pyrite) which is normally precipitated in clays laid down at moderate depth.

The Nothe Grit at Lynch Cove yields an ammonite fauna indicative of the Cordatum Subzone, the highest subzone of the Cordatum Zone. The fauna is well preserved in calcareous concretions, along with numerous bivalves indicating a wide variety of habitats, from the deep-burrowing *Pleuromya*, through shallow-burrowing forms such as *Myophorella*, to numerous cemented, surface-dwelling forms such as *Liostrea* and *Nanogyra*. The Nothe Grit thus demonstrates the characteristic fauna of an offshore marine sand laid down under comparatively gentle, non-turbulent conditions. This can be contrasted with the fragmental nature of the fauna of the overlying Preston Grit, laid down under shallower, more turbulent conditions.

Conclusions

Arkell's systematic collection of ammonites and bivalves from the Red Nodule Bed at this site (Arkell, 1939b, 1947a), together with his similar collection from the unit at the Osmington site (this volume), demonstrates that this is a highly significant exposure, one of only three in England yielding ammonites of the Costicardia Subzone. In addition, this is one of the few localities in southern England where the well-preserved ammonite fauna found in the overlying Nothe Grit can be collected.

TYNEHAM CAP–HOUNSTOUT (SY 888 796–SY 956 768)

B.M. Cox

Introduction

This GCR site comprises the magnificent cliff and foreshore exposures of Kimmeridge Clay between Brandy Bay and Chapman's Pool on the Dorset coast (Figures 2.25 and 2.26). It includes Kimmeridge Bay, which gives its name to the Kimmeridge Clay Formation and the Kimmeridgian Stage, and is therefore a site of international renown. The cliffs at Brandy Bay and Hobarrow Bay, and eastwards to the western end of Kimmeridge Bay, fall within the Ministry of Defence's Lulworth Gunnery Range. The Kimmeridge Clay was first recognized as a discrete unit (called 'Oaktree Soil') by William Smith on his map of 1815 although subsequently he called it 'Oaktree Clay'. The first descriptive details were provided by Webster (1816), who changed the name to Kimmeridge Clay. Arkell (1947a) introduced names for nearly all the subdivisions of the formation at and adjacent to Kimmeridge Bay (e.g. Cattle Ledge Shales, Hen Cliff Shales, Maple Ledge Shales, Gaulters Gap Shales, Washing Ledge Shales), each being defined as the beds between particularly prominent limestone bands, but these names are of little value except in these coastal sections and

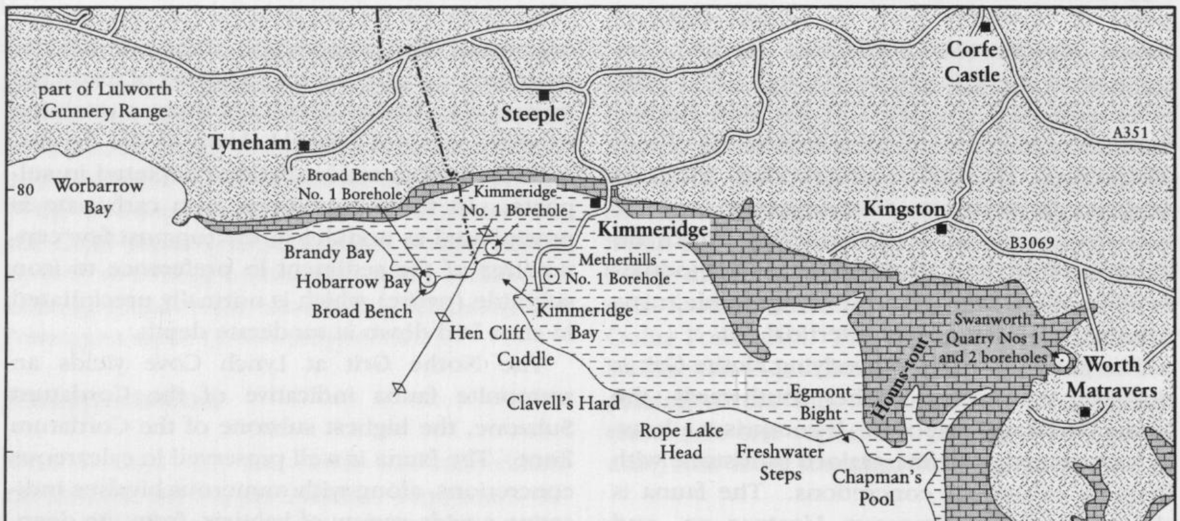

Figure 2.25 Sketch map of the solid geology of the Kimmeridge area, (based on Cox and Gallois, 1981, fig. 7 and Gallois, 2000, fig. 1).

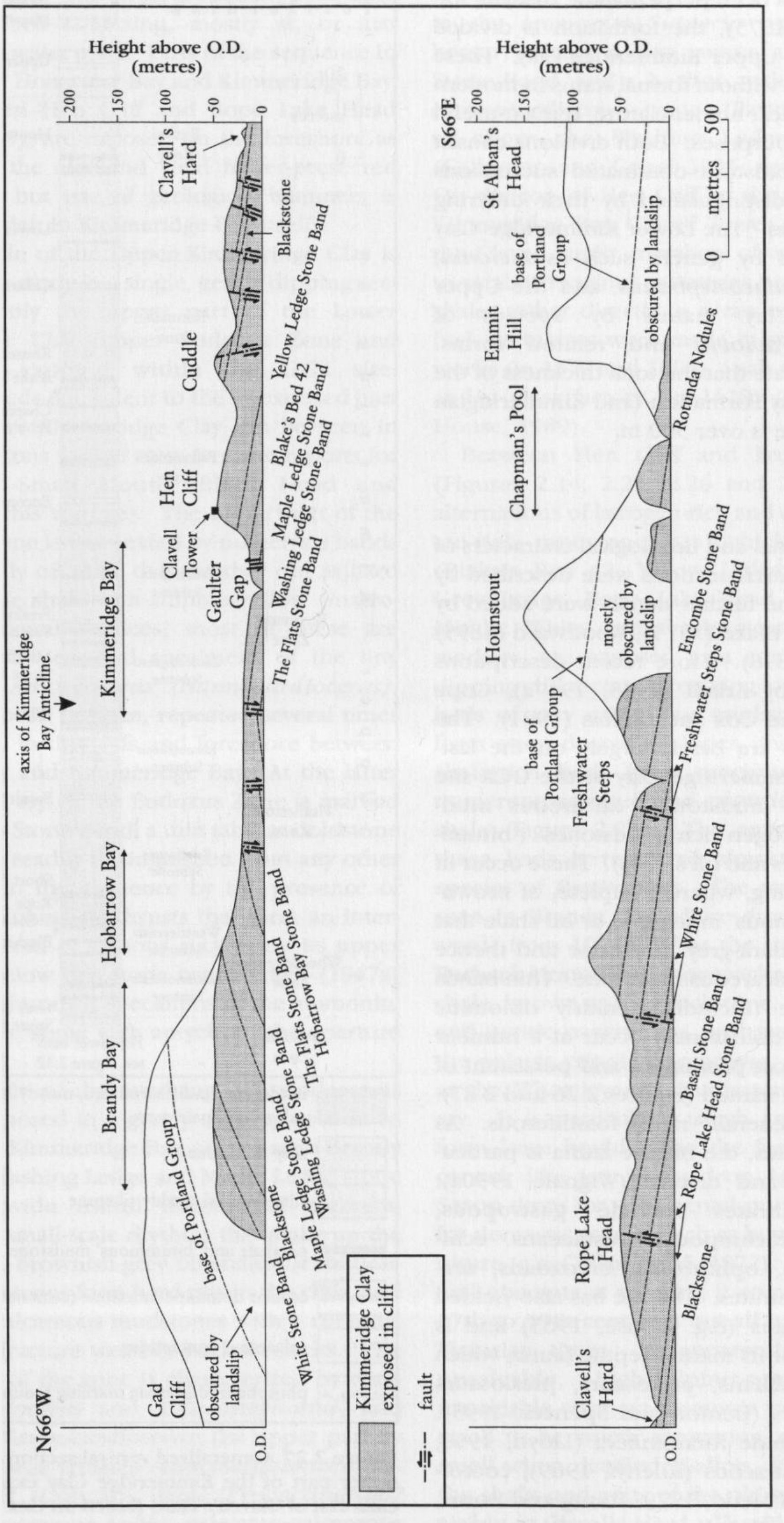

Figure 2.26 Geological sketch sections of the Kimmeridge Clay exposed in the cliffs between Brandy Bay and Chapman's Pool (based on Cox and Gallois, 1981, fig. 8 and Gallois, 2000, fig. 2).

their use has not been perpetuated. Instead, following Blake (1875), the formation is divided into Lower and Upper Kimmeridge Clay. These terms, although without formal status in modern lithostratigraphical nomenclature, remain useful for descriptive purposes. Both divisions consist of rhythmic, mudstone-dominated successions but are easily distinguished by their differing ammonite faunas. The Lower Kimmeridge Clay is characterized by genera such as *Pictonia*, *Rasenia* and *Aulacostephanus*, and the Upper Kimmeridge Clay mainly by species of *Pectinatites*, *Pavlovia* and related forms. Boreholes indicate that the total thickness of the Kimmeridge Clay Formation (and Kimmeridgian Stage) at the site is over 500 m.

Description

The general faunal and lithological characters of these Dorset coastal sections were described by Fitton (1836) and further details were added by Waagen (1865), Blake (1875), Woodward (1895) and Strahan (1898). More recent descriptions include those by Arkell (1933, 1947a), Cope (1967, 1978) and Cox and Gallois (1981). The following notes are based largely on the last-named. The Kimmeridge Clay at the GCR site comprises soft mudstones, calcareous mudstones and kerogen-rich mudstones ('bituminous' mudstones and oil shales). These occur in rhythms consisting, where complete, of brownish-grey 'bituminous' mudstone or oil shale that passes up into dark-grey mudstone and thence into pale-grey calcareous mudstone. Thin bands of cementstone (including muddy dolomitic limestones, i.e. dolostones) occur at a number of levels; the most prominent and persistent of these have been named (Figures 2.26 and 2.27). The beds are generally richly fossiliferous. As well as ammonites, the bivalve fauna is particularly abundant and diverse (Wignall, 1990a). Other invertebrates include gastropods, scaphopods, brachiopods, crustaceans, echinoids, crinoids, ophiuroids, bryozoans, serpulids and belemnites. The site has also yielded fossil fish remains (e.g. House, 1965) and is world-famous for its marine reptile fauna, which includes crocodilians, pterosaurs, plesiosaurs and ichthyosaurs (Benton and Spencer, 1995). Microfossils include foraminifera (Lloyd, 1958, 1959, 1962), ostracods (Kilenyi, 1969), coccoliths (Gallois and Medd, 1979; Young and Bown, 1991) and dinoflagellate cysts (Riding and

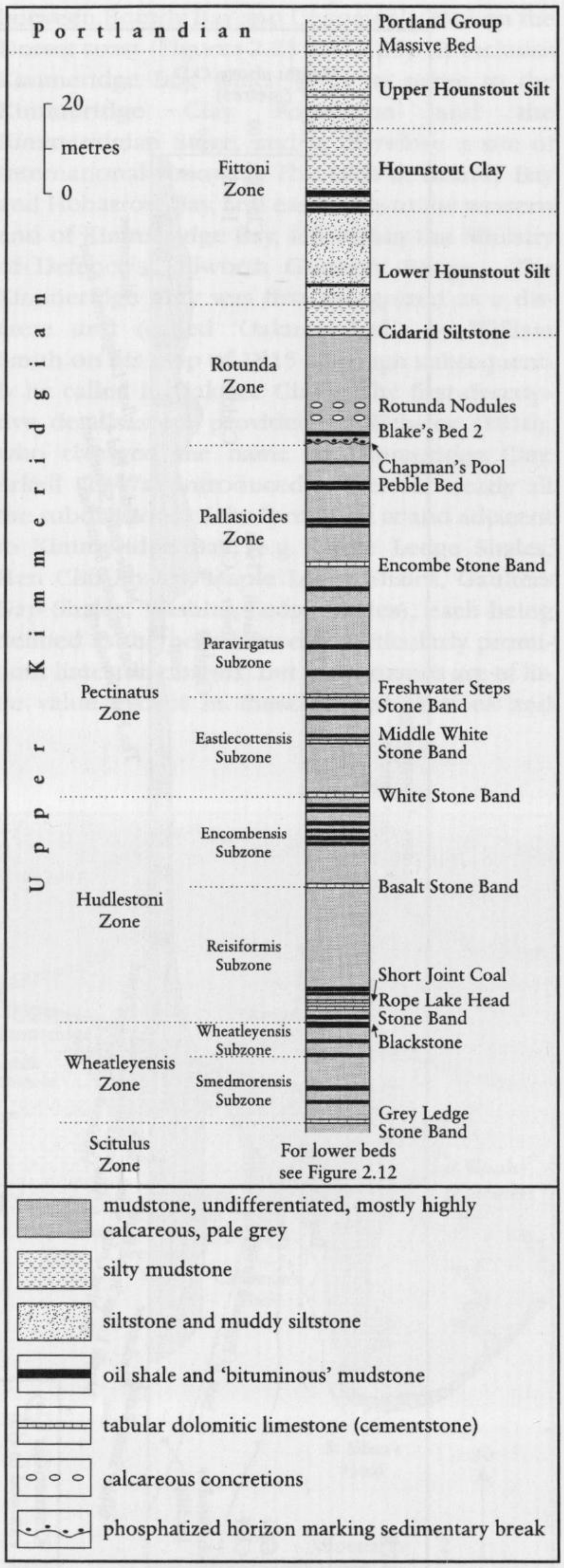

Figure 2.27 Generalized vertical section through the upper part of the Kimmeridge Clay exposed in the cliffs east of Clavell's Hard (based on Cox and Gallois, 1981, fig. 13 and Gallois, 2000, figs 4 and 6).

Thomas, 1988). The strata are readily accessible for bed-by-bed collecting, mostly at, or just above, high water mark. Parts of the sequence in Brandy Bay, Hobarrow Bay and Kimmeridge Bay, and between Hen Cliff and Rope Lake Head (Figure 2.25), are exposed on the foreshore as well as in the cliff and yield better-preserved specimens, but use of geological hammers is now forbidden in Kimmeridge Bay itself.

The whole of the Upper Kimmeridge Clay is available for study in a single, gently dipping section but only the upper part of the Lower Kimmeridge Clay (upper Eudoxus Zone and above) is exposed within the GCR site. However, beds equivalent to the unexposed part of the Lower Kimmeridge Clay can be seen in coastal sections further west (see site reports for East Fleet–Small Mouth, Black Head and Ringstead, this volume). The upper part of the Eudoxus Zone is dominated by numerous bands of very shelly oil shale that weather out as hard ribs of fissile shale with sulphur-yellow (?natrojarosite) coated surfaces; most of these are crowded with crushed specimens of the tiny ammonite *Amoeboceras (Nannocardioceras)*. These beds can be seen, repeated several times by faulting, in the cliffs and foreshore between Brandy Bay and Kimmeridge Bay. At the latter locality, the top of the Eudoxus Zone is marked by the Flats Stone Band, a thin tabular dolostone that can be readily distinguished from any other limestone in the sequence by the presence of numerous low-angle thrusts that form an intersecting pattern of sinuous ruckles on its upper surface. Below this stone band, Arkell (1947a) described abundant specimens of the ammonite *Aspidoceras*, some with aptychi in the aperture of the shell.

The whole of the overlying Autissiodorensis Zone is exposed in a gently dipping section in the cliffs at Kimmeridge Bay, as well as in Brandy Bay. The Washing Ledge and Maple Ledge stone bands provide useful lithological markers. Within the small-scale rhythms that make up the succession, brownish-grey oil shales or 'bituminous' mudstones form hard ribs in the cliffs, and pale-grey calcareous mudstones with a cuboidal or 'dicey' fracture weather back as slacks. The lower part of the zone is characterized by common *Aspidoceras* and *Aulacostephanus*, and abundant *Nannocardioceras*; the upper part by abundant large crushed *Aulacostephanus autissiodorensis* (Cotteau), large *Propectinatites?* (relatively common in the pale-grey calcareous mudstones) and rare *Gravesia*. A thin bed rich in the ammonite *Sutneria rebholzi* (Berckhemer) occurs a few metres above the Flats Stone Band, and a horizon with the ammonite *Nannocardioceras volgae* (Pavlow) occurs *c.* 4 m above the Washing Ledge Stone Band (Callomon and Cope, 1995; see Figure 2.14). On the top of Hen Cliff, at the eastern end of Kimmeridge Bay, Clavell Tower commemorates the Clavell family, members of which attempted to establish various industries here using the oil shales either directly as a raw material, or as a fuel. Attempts were made at starting an alum works (in 1570 and 1605), a salt works (in 1610) and a glass factory (in 1618) (Crossley, 1987; House, 1989).

Between Hen Cliff and Freshwater Steps (Figures 2.14, 2.25, 2.26 and 2.27), rhythmic alternations of kerogen-rich and calcium carbonate-rich mudstones, in which stone bands (Blake's Bed 42, Yellow Ledge, Cattle Ledge, Grey Ledge, Rope Lake Head, Basalt, White, Middle White and Freshwaters Steps) act as markers, are exposed in a continuous, gently dipping cliff section stretching for *c.* 4 km. Thick beds of very calcareous mudstone weather to form steep degraded slopes, and groups of oil-shale-rich beds form precipitous cliffs with numerous serrated and protruding ribs of oil shale (Figure 2.28). The ammonite fauna of these beds is restricted almost exclusively to species of *Pectinatites*. The same sequence is seen in Brandy Bay where dips increase westwards from 10° to 20° as the steep limb of the Purbeck Monocline is approached. A massive oil shale, known as the Blackstone, with calcareous and pyritic concretions, and pyritized plates of the pelagic crinoid *Saccocoma*, forms a marker at the Wheatleyensis–Hudlestoni zonal boundary. It is particularly tough and fallen blocks form large boulders on the foreshore. It was carved, like jet, in the Iron Age, Roman and Saxon times for ornamental purposes as well as for domestic articles such as bowls and even furniture (e.g. Calkin, 1955, 1972). There were several attempts at working it commercially in the 17th to 19th centuries but all had failed by late Victorian times. It apparently produced an unsaleable, high-sulphur-content oil, an unsaleable coke, an ammonia yield that was too small to be worth recovering and an offensive smell when distilled (Gallois, 1979a). Some of the shafts and adits of the old workings are still visible at Clavells Hard. The Blackstone ignites

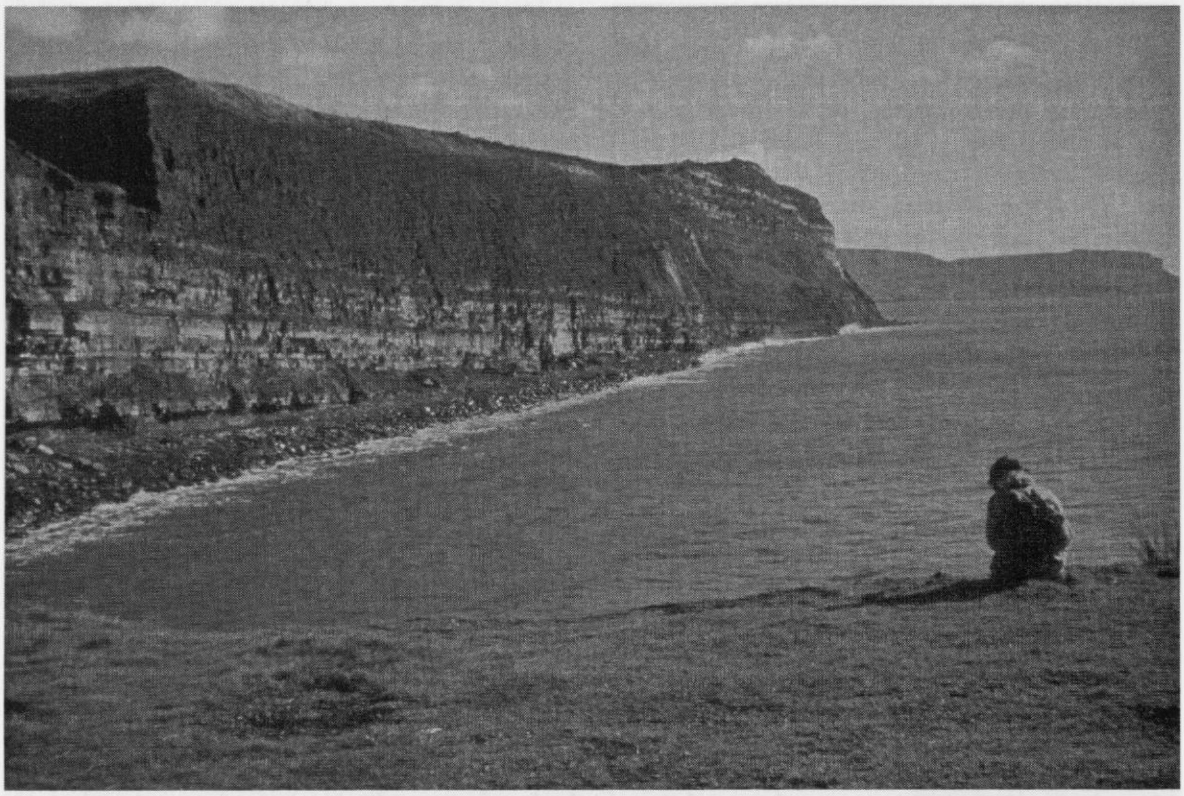

Figure 2.28 Looking east from Clavell's Hard to Rope Lake Head and St Alban's Head (far distance). The lower part of the cliff face comprises alternating mudstones and ribs of oil shale including the Blackstone, Rope Lake Head Stone Band and Short Joint Coal. The upper part comprises a thick succession of pale calcareous mudstones including, towards the top, the Basalt Stone Band. The cliff is capped by further alternations of mudstone and oil shale including the White Stone Band. (Photo: W.A. Read.)

readily and spontaneous combustion has been reported (Cole, 1974, 1975) although House (1989) considered such claims to be spurious and the fires, which may burn or smoulder for some years, to have been manmade. Some pink colouration of the bed indicates where it has been burnt in recent years.

From Freshwater Steps to Chapman's Pool, the coastal exposures of Kimmeridge Clay comprise uniform, very calcareous mudstones in which a few lines of limestone doggers and some thin, weakly developed oil shales form markers. Without resistant stone bands or oil shales, the beds form steep degraded slopes which, in places, have been overridden by slipped masses of the topmost Kimmeridge Clay and succeeding Portland Group; a complete succession is nonetheless present. A weakly cemented, very pale mudstone, seen *c.* 30 m above the Freshwater Steps Stone Band in Egmont Bight, has been named the Encombe Stone Band by Gallois (2000); it is a well-defined stone band in boreholes in the area. At Chapman's Pool, thin oil shale and 'bituminous' mudstone seams are again present and form prominent hard ribs in the cliff and ledges on the foreshore. The section, up to the base of the Portland Group, was summarized by Arkell (1933, 1947a) and later described by Cope (1978), but the exposures, which are deeply weathered, partially landslipped and poorly accessible, have recently been reassessed by Gallois (2000) with the help of data from nearby cored boreholes. Two lines of small calcareous concretions (the Rotunda Nodules), 3 and 6 m above the highest oil shale (Blake's Bed 2), provide a useful marker. They contain uncrushed and partially crushed 'pavloviid' ammonites including *Pavlovia rotunda* (J. Sowerby) which gives its name to the Rotunda Zone. A few metres below Blake's Bed 2, Gallois (2000) identified a gritty, silt-rich mudstone, up to a few centimetres thick, with abundant belemnites and oysters as well as phosphatized bivalves and 'pavloviid' ammonite body chambers. This bed, which he named the Chapman's Pool Pebble Bed, rests on a bioturbated surface and marks an important sedimentary break and faunal change at the base of the Rotunda Zone. Another new marker horizon recognized by Gallois (2000 and pers. comm.) in the cliffs here is the Cidarid Siltstone. It occurs about 15 m above the Rotunda Nodules and contains a rich and diverse fauna including oysters, the pectinid bivalve *Entolium*, belemnites (*Hibolithes*) and cidarid spines. The overlying beds, up to the base of the Portland Group, have traditionally been divided, in ascending sequence, into the Lingula Shales, Rhynchonella Marls, Hounstout Clay and Hounstout Marl – terms that originate with Buckman (1925–1927) or Arkell (1933). However, Gallois (2000) used instead the terms 'Lower Hounstout Silt', 'Hounstout Clay' and 'Upper Hounstout Silt', as shown in Figure 2.27, because they reflected better the broad lithological characters (mainly siltstone, muddy siltstone or silty mudstone) of the succession. The main marker in this interval is a cluster of three thin 'bituminous' mudstones at the base of the Hounstout Clay.

Interpretation

In recent years, much interest has been shown in the exposures of Kimmeridge Clay that constitute this GCR site and they have been intensively investigated by academics and petroleum geologists because the formation is a principal source rock in the North Sea Basin where it occurs at depth. This has led to an extensive literature, particularly in the fields of sedimentology, geochemistry, palaeoecology and sequence stratigraphy (Cosgrove, 1970; Gallois, 1979a; Irwin, 1979, 1980, 1981; Tyson *et al.*, 1979; Aigner, 1980; Farrimond *et al.*, 1984; House, 1985; Williams, 1986; Myers and Wignall, 1987; Scotchman, 1987a, b, 1989, 1991a, b; Astin and Scotchman, 1988; Oschmann, 1988; Wignall and Myers, 1988; Wignall, 1989, 1990a, 1991, 1994; Coe *et al.*, 1990; Wignall and Ruffell, 1990; Herbin *et al.*, 1993; MacQuaker and Gawthorpe, 1993, 1994; Herbin *et al.*, 1995).

The lower boundary of the formation is not exposed within the site although it was cored in the nearby Metherhills No.1 Borehole (Gallois, 2000). The upper boundary, with the overlying Portland Group, is seen in the cliff face (Hounstout) above Chapman's Pool. Arkell (1933) summarized the reasons given by previous authors, from Fitton (1836) to Cox (1929), for their individual choices of this boundary, which Arkell (1933, 1947a) placed at the base of a prominent bed of sandstone known as the 'Massive Bed'. Most subsequent authors have followed this despite Townson's (1975) detailed sedimentological work, which suggested that a more appropriate place for the lithostratigraphical boundary was lower down at the base of the Rhynchonella Marls. He considered this position to represent a downward mappable change from silts to shale. It is only on the Dorset coast that the positioning of this boundary is controversial; elsewhere, the highest beds of the Kimmeridge Clay have been removed and the base of the Portland Group rests on an erosion surface. According to Gallois (2000 and pers. comm.), the thickness of 66 m given by Cope (1978) for the beds between the Rotunda Nodules and the base of the Massive Bed is underestimated by up to 12 m.

In contrast to the lithostratigraphical boundary, there has been no dissent from the choice of the Massive Bed as the Kimmeridgian–Portlandian stage boundary assuming the traditional British usage of those terms (see Chapter 1). The coastal sections here have played an important part in the development of the ammonite-based standard zonation for the Kimmeridgian Stage. The zonally diagnostic ammonite genera here are *Aulacostephanus* for the Eudoxus and Autissiodorensis zones (Ziegler, 1962), and *Pectinatites*, *Pavlovia* and *Virgatopavlovia* for the higher zones (Cope, 1967, 1978). The stage is divided into Lower and Upper. The boundary between these two substages has traditionally been taken at the base of the stone band known as Blake's Bed 42, which crops out in Hen Cliff, and which forms one of the famous 'Kimmeridge Ledges' on the adjoining foreshore, just east of Kimmeridge Bay. However, for consistency with other English sections, Gallois (2000) suggested that the substage boundary should instead be taken at the base of the first oil shale above the highest recorded *Aulacostephanus*, which is *c.* 7 m below Blake's Bed 42. This part of the section is particularly important because it correlates with the basal beds of the Tithonian Stage; in recent years, the latter has been ratified by the International Subcommission on Jurassic Stratigraphy (ISJS) as the primary terminal

Jurassic stage for international usage. The ammonite provincialism in the Late Jurassic and the different stage nomenclatures to which it has given rise do not need to concern us here, but the section at Hen Cliff is nonetheless of international importance because, although the term 'Tithonian' is not applied to the British succession, the locality is a potential auxiliary boundary stratotype or reference section for the base of that stage. The occurrence of the ammonite genus *Gravesia* is of particular importance in this respect because its geographical distribution is relatively widespread thus enabling international correlation. It ranges from 3 m below the Maple Ledge Stone Band up to 1.8 m above the Yellow Ledge Stone Band (Cox and Gallois, 1981; Callomon and Cope, 1995) (Figure 2.14).

The palaeoecology of the Kimmeridge Clay exposed at this site was investigated by Wignall (1990a) on the basis of the benthic macrofauna amongst which bivalves are predominant. He concluded that the thick sequences of rhythmic organic-rich shales and mudstones of the upper Eudoxus Zone–middle Wheatleyensis Zone were deposited in an offshore basinal area where low-diversity populations of opportunists, such as the bivalves *Corbulomima* and *Protocardia*, colonized during brief oxygenation events. The sediments were generally fairly soft and excluded most epifaunal forms. According to Wignall (1989), who logged all the sedimentary features in the Kimmeridge section, the principal mechanism for supplying oxygen to the sea-bed environment was storms. Organic-rich and oxygen-restricted bottom waters characterized the depositional environment of the overlying sediments up to the upper part of the Pectinatus Zone. Relative to other areas of southern and eastern England, the mudstones at these latter levels on the Dorset coast, which contain the ubiquitous bivalve *Protocardia* and the patellid gastropod *Pseudorhytidopilus*, were deposited in a deeper-water, more offshore environment. Epifaunal forms are more common, suggesting that substrates were firmer and, by implication, sedimentation rates were slower than previously. Within the sediments of the Hudlestoni Zone, Wignall and Ruffell (1990) combined palaeoecological investigations and biofacies analysis with clay mineralogy and geochemistry to suggest evidence of a sudden palaeoclimatic change from humid to semi-arid. From the upper part of the Pectinatus Zone to the top of the Kimmeridgian, organic-rich shale deposition became progressively more restricted to the centres of the offshore basins such that on the Kimmeridge coast the facies persists into the basal part of the Rotunda Zone. The benthic faunas of the latest Kimmeridgian become much more diverse and indicate better-oxygenated shallower marine conditions. Wignall (1989) also concluded that the proportion of organic-rich shales was the most reliable indicator of palaeobathymetry, with the main areas of organic-rich shale deposition occupying the deepest water sites.

The dolomitic limestones (dolostones), which form prominent ribs and ledges (some of the so-called 'Kimmeridge Ledges') in the cliffs and foreshore in and adjacent to Kimmeridge Bay, usually weather to a greyish-yellow or even orange surface colour owing to the presence of the mineral ankerite ($Ca(Mg,Fe)(CO_3)_2$). They formed by diagenetic replacement of a pre-existing lithology (mudstones or shales) in the methanogenic zone (*c.* 10 m to *c.* 1000 m burial depth), probably at several hundred metres burial depth (Irwin *et al.*, 1977). They are confined to basinal depositional settings where methanogenic processes prevailed. Dolostone formation requires substantial quantities of metabolizable organic matter to survive to relatively great burial depth; this can be accomplished by rapid burial of organic matter through the near-surface sulphate reduction zone (Wignall and Ruffell, 1990). By contrast, calcareous nodules or limestone doggers, which occur in the highest beds of the Kimmeridge Clay, require prolonged residence time in the sulphate reduction zone (up to 10 m burial depth), and are common over high/swell depositional settings. Thus, dolostones and limestone nodules do not co-occur in the Kimmeridge Clay.

The Rope Lake Head, White, Middle White and Freshwater Steps stone bands and the Short Joint Coal, a thin limestone close above the Rope Lake Head Stone Band, are examples of the coccolith-rich bands first identified by Downie (1957) (Gallois and Medd, 1979). Gallois and Cox (1974) suggested that the White Stone Band, which is a particularly well developed and widespread example, formed from an algal bloom. Of the 11 bands identified by Gallois and Medd (1979), all but one are interlaminated with oil shales, and the beds themselves, particularly the White and the Freshwater Steps stone bands, show distinct lamination. Gallois (1976) suggested that the interlamination may have resulted from alternating coccolith and dinoflagellate blooms.

All recent sedimentological studies of the Kimmeridge Clay are agreed that the preservation of abundant organic matter was caused by stagnant bottom waters (Sellwood and Wilson, 1990) but various theories have been proposed to explain how these conditions, and the rhythmic variations of which they are part, came to be. Gallois (1976) suggested that land-derived nutrients stimulated blooms of phytoplankton (coccoliths and dinoflagellates) (see above), the decay of which led to temporary oxygen-deficient or hydrogen sulphide-rich zones in which organic material could accumulate and be preserved. On the other hand, Tyson *et al.* (1979) suggested that phytoplankton blooms were a symptom of widespread anaerobic bottom conditions rather than their cause, and that the lithological rhythms are best interpreted in terms of water-column stratification and occasional sea-floor anoxia. They proposed a stratified water column in which a basal hydrogen sulphide-rich zone periodically extended up through the water column. 'Bituminous' shales formed as the top of the latter zone moved from just beneath the sediment surface to just above it. Oil shales formed when the oxygen:hydrogen sulphide interface was quite high in the water column, and laminated coccolith-rich limestones formed when the oxygen:hydrogen sulphide interface reached the euphotic zone. Seasonal temperature variations or storm-induced activity resulted in the mixing of the oxygen- and hydrogen sulphide-rich layers so that the nutrients of the latter stimulated phytoplankton (coccolith) blooms and the oxygen at the hydrogen sulphide:oxygen interface killed off bacteria that thrived in the euphotic part of the hydrogen sulphide layer. Tyson *et al.*'s (1979) hypothesis is compatible with current interpretations of the Black Sea and Nile Cone sea-floor sediments.

Although it is commonly accepted that stratification in the Kimmeridge Clay seas was caused by the presence of thermoclines (Tyson *et al.*, 1979; Myers and Wignall, 1987), the ultimate cause of the cyclic stratification has still not been fully resolved (Wignall, 1989). The suggestion that the stratification was salinity-induced (Scotchman, 1984) has not found favour, nor has Oschmann's (1985) idea that the bottom waters in the thermally stratified water column were derived from upwelling of cold, nutrient-rich, oxygen-poor waters from the Arctic Ocean. Wignall (1989) reported volcanically induced changes of climate (Zimmerle, 1985) or orbitally forced climatic changes (Hallam, 1986) as the two main alternatives, and concluded that Milankovitch-type cyclicity may have been the main control (Dunn, 1974; House, 1985, 1986, 1989, 1995; Waterhouse, 1995).

Conclusions

The cliff and foreshore exposures at and adjacent to Kimmeridge Bay in Dorset provide tectonically uncomplicated, continuous sections through the greater part of the Kimmeridge Clay Formation. They are readily accessible and consist of thick sequences of fossiliferous marine mudstones, apparently free from major non-sequences. The cliffs between Brandy Bay and Freshwater Steps are being actively eroded and fresh sections are almost always available. On the English mainland, the formation extends northwards to North Yorkshire but it is poorly exposed inland and much of our understanding of its stratigraphy has been made through study of the Dorset coastal sections (see also site reports for East Fleet–Small Mouth, Black Head and Ringstead, this volume). The locality also gives its name to the Kimmeridgian Stage, which has been an international unit of stratigraphical classification and correlation for nearly 150 years. In recent years, the exposures at this site have been intensively studied because of the occurrence of oil shales within the Kimmeridge Clay and the role of that formation, where it is buried at depth, as a principal source rock for North Sea oil. The possible causes of the well-displayed lithological rhythmicity of the succession and its relevance to the interpretation of past and possible future climates has also been investigated in recent years.

BLIND LANE (SY 576 856)

B.M. Cox

Introduction

The village of Abbotsbury, Dorset, is located on the south-westernmost outcrop of Kimmeridgian strata on the English mainland (Figure 2.12). Sited *c.* 13 km west of the coastal sections near Weymouth (see site report for East

Fleet–Small Mouth, this volume), the locality is famous for the Abbotsbury Iron Ore (now generally known as the 'Abbotsbury Ironstone') which crops out on three sides of the village, dipping beneath it from the north, west and south in an E–W-trending synclinal structure (Arkell, 1947a). In the past, it has been well exposed in the lanes both north and, to a lesser extent, south of the village. It attracted the attention of Sedgwick (1826) and, later, Damon (1860), Blake and Hudleston (1877), Woodward (1895) and Strahan (1898). Subsequent accounts by Arkell (1933, 1936, 1947a) and Brookfield (1973b, 1978) have concentrated on the stratigraphical position, palaeontology, palaeoecology and depositional environment of the ironstone, which is unique in the British Kimmeridgian. Wilson *et al.* (1958) reported the various exposures that were available at the time of their geological survey. Although the ironstone has a substantial iron content of at least 30%, it has not been worked extensively because of its high silica content (Pringle in Lamplugh *et al.*, 1920); Arkell (1936) commented that this had fortuitously prevented 'one of the loveliest of English village settings' from being spoilt.

Description

A section in Blind Lane, at the western end of Jubilee Coppice, comprises the GCR site (Figure 2.29). According to Callomon and Cope (1995), this is the most readily accessible exposure and shows the ironstone dipping to the south into the small syncline that runs through Abbotsbury. From the site, there is a view of St Catherine's Chapel, which stands on the dip slope on the southern limb of the syncline. There is some confusion in the geological literature, even amongst individual authors, concerning the names of the lanes on the north side of the village. Although now known as 'Blind Lane', some authors have referred to it as 'Red Lane', whilst others have used the latter name for the lane further west, opposite the Ilchester Hotel, which is indeed the modern Red Lane. There is also confusion amongst authors about which of

Figure 2.29 Exposure of Abbotsbury Ironstone at Blind Lane, Abbotsbury. (Photo: A6478, reproduced with kind permission of the Director, British Geological Survey ©NERC.)

these two lanes is that referred to by Blake and Hudleston (1877;'the road leading over the hill to Gorwell'), and Pringle (in Lamplugh *et al.*, 1920; 'the lane leading from Abbotsbury to Gorwell Gate'). In either case, the sections produced by Blake and Hudleston (1877) and Pringle (in Lamplugh *et al.*, 1920) are closely similar, as noted by Arkell (1936). The latter's published section (including bed numbers) forms the basis of that given below, which includes some added detail from House (1989). The lithostratigraphical classification is based on Brookfield (1978).

	Thickness (m)
Abbotsbury Ironstone	
6. Sand, yellowish brown, ferruginous, veined by thin seams of limonite	1.8–2.4
5. Ironstone, reddish brown; ferruginous ooids as shining 'millet-seed' grains in matrix of fine-grained quartz sandstone; interbeds of concretionary ironstone and ferruginous mudstone; abundant fossils including brachiopods, bivalves, gastropods, ammonites, serpulids and fossil wood; harder band of sandstone near base	6.0
Abbotsbury Sandstone	
4. Sandstone, dark brown, coarse-grained; ferruginous peloids; ammonites	0.8
3. Sand, soft, weathering yellow	0.6
2. Sandstone, dark brownish green, ferruginous	0.3
1. Sandstone, brown, ferruginous; variably cemented; fossils preserved as casts	*c.* 3.0

All outcrops are oxidized and the iron ore is red or reddish brown in colour except where seen in deep trenches when it appears green owing to the presence of the iron silicate mineral berthierine, commonly (though incorrectly) referred to as 'chamosite'; much of the berthierine is now weathered to limonite (House, 1989). Bed 6 of the above section may be merely the weathered upper portion of the ironstone Bed 5 (Arkell, 1936).

Interpretation

The lithostratigraphical classification of the Abbotsbury Ironstone has not been straightforward, not least because authors have been influenced by its chronostratigraphy rather than following strict lithostratigraphical principles. Arkell (1936) described the Abbotsbury Ironstone as forming an upward lithological continuation of the 'already ferruginous Sandsfoot Grits' of the Corallian Group but the fact that it contains the ammonite *Rasenia* (Arkell, 1933, 1936, 1947a), indicative of the Lower Kimmeridgian Cymodoce Zone, has led many authors to consider it as part of the Kimmeridge Clay Formation. In their paper on the Corallian of England, Blake and Hudleston (1877) correctly surmised that it occurred 'at least on the horizon of the passage-beds to the Kimmeridge Clay'. Although Wilson *et al.* (1958) used the term 'Passage Beds' when they mapped the Abbotsbury area, because they were unable to recognize what they considered to be an orthodox Corallian Beds–Kimmeridge Clay boundary, Brookfield's (1978) attempt to revive Blake's (1875) idea of a Passage Beds Formation for this interval (with the Abbotsbury Ironstone as its youngest unit) has not found acceptance (see site report for East Fleet–Small Mouth, this volume). Brookfield (1978) replaced the term 'Sandsfoot Grits', as used by Arkell (1936) for the beds beneath the Abbotsbury Ironstone, by the term 'Abbotsbury Sandstone' because he considered that they were not part of the same depositional episode responsible for the Sandsfoot Grit of the Dorset coast. According to Brookfield (1978), the Abbotsbury Sandstone dies out about 3 km east of Abbotsbury and is not in lateral continuity with the Sandsfoot Grit of the coastal exposures. He believed it was younger than the Sandsfoot Grit, which it overlaid, and that it was the correlative of the Ringstead Clay and basal Kimmeridge Clay of the coastal sections. According to Brookfield (1978), the top of the Abbotsbury Sandstone could then be seen at the GCR site (called by him 'Red Lane') where it belonged to the lower part of the Cymodoce Zone. All published accounts agree that the boundary between the Abbotsbury Ironstone and underlying Abbotsbury Sandstone is gradational. If the latter is in lateral and/or vertical continuity with the Sandsfoot Grit, as recent geological surveying suggests (C.R. Bristow, pers. comm.) then there appears to be no lithostratigraphical justification for excluding the beds up to and including the Abbotsbury Ironstone from the Corallian Group. There is neither a lithological change nor an event horizon (Inconstans Bed) comparable with those that define the base of the Kimmeridge Clay in its type area (see site reports for Black Head and Ringstead, this volume), and the base of that formation in the Abbotsbury area is most appropriately drawn at the top of the Abbotsbury Ironstone. Blake and Hudleston's (1877) record of the brachiopod ***Rhynchonella*** (***Torquirhynchia***) ***inconstans*** J. Sowerby (and, by inference, the Inconstans Bed) refers to ***?Septaliphora hudlestoni*** (Rollier) (Childs, 1969), asymmetrical variants of which have often been mistakenly recorded as *T.* ***inconstans*** (Brookfield, 1973b).

A full faunal list for the Abbotsbury Ironstone was given by Brookfield (1978), updated from Brookfield (1973b). This included 17 bivalve taxa (the taxonomically most diverse group) together with gastropods, brachiopods, ammonites, a nautiloid, a serpulid, an echinoid and a crustacean. According to Cope (1980), the species of ***Rasenia*** that characterize the Abbotsbury Ironstone constitute a distinctive fauna that is different from that of the four ***Rasenia*** faunal horizons recognized by Birkelund *et al.* (1978) (see site report for East Fleet–Small Mouth, this volume). Callomon (in Cope, 1980) believed it was closest to, and possibly identical with, that of the 'Marnes à Pterocères' at Villerville in Normandy, which yielded the type specimens of ***Rasenia erinus*** (d'Orbigny) and ***R. berryeri*** (Dollfus). Specimens from the Abbotsbury Ironstone comparable with the former species were illustrated by Morris (1968) in his unpublished thesis. There is no definitive evidence for the age of the underlying Abbotbury Sandstone. Blake and Hudleston (1877) reported 'numerous ***Ammonites decipiens***' but no one has been able to substantiate this record. Arkell (1947a) suggested they might be ***Pictonia*** or ***Ringsteadia*** but was not able to verify this. Morris (1968) reported that these beds had 'yielded only one ammonite which may be referred to the Pictoniinae but is not sufficiently well preserved to be of any stratigraphical value'. The few bivalve records are not age diagnostic. On the basis of this evidence, one can only conclude that Brookfield's (1978) Abbotsbury Sandstone is Late Oxfordian and/or Early Kimmeridgian in age. Future detailed palaeontological work on cores from two recent British Geological Survey boreholes at Abbotsbury (Newell, 2000) may provide additional useful data.

Although bivalves dominate the fauna of the Abbotsbury Ironstone taxonomically, brachiopods are locally more abundant. The brachiopod fauna is rich and varied for the British Kimmeridgian (Sandy, 1985). The rhynchonellid ***?Septaliphoria hudlestoni*** has already been mentioned but, in addition, Brookfield (1973, 1978) recorded ***'Terebratula' subsella*** (Leymerie), ***Ornithella lampas*** (J. Sowerby), ***Aulacothyris dorsetensis*** (Davidson) and ***Lingula*** sp.. Following investigation of the internal shell structures, Sandy (1985) reassigned the specimens previously identified as ***Aulacothyris dorsetensis*** to the genus ***Rugitela***, and indicated that the ***'Terebratula' subsella*** belonged to the genus ***Kutchithyris***.

The faunal and lithological characteristics of the Abbotsbury Ironstone suggest a near-shore depositional environment or, more likely, because of the lack of any indications of shoreline or strand, or sediment derived from south-west England, an environment marginal to an offshore (barrier) bar facing south-east (Brookfield, 1973). This scenario, analogous to the present-day barrier bar environments of the Gulf of Mexico, was apparently terminated by a marine transgression that brought relatively quiet water and mud (Kimmeridge Clay) deposition to the area (Brookfield, 1973).

Conclusions

The village of Abbotsbury in Dorset is sited on the outcrop of the Abbotsbury Ironstone that represents a unique deposit in the British Kimmeridgian. The ironstone, comprising (when fresh) berthierine ooids in a fine-grained quartz sandstone matrix, was once worked on a small scale but has never been fully exploited for iron because of its high silica content. It has, however, been much used locally as a building stone. The GCR site offers a readily accessible exposure in one of the lanes leading northwards from the village. The Abbotsbury Ironstone has yielded a rich benthic fauna, including an unusually rich and varied brachiopod fauna, as well as age-diagnostic ammonites of the genus ***Rasenia***. Known only at Abbotsbury, this unique and unusual deposit is interpreted as representing an Early Kimmeridgian offshore barrier bar.

WESTBURY (ST 853 508)

J.K. Wright

Introduction

Westbury Iron Ore Mine has been renowned since the mid-19th century as containing the best-quality accumulation of oolitic ironstone in the British Corallian, as represented by the Upper Oxfordian Westbury Ironstone Formation. The ironstone was first discovered by Greenwell (1859), and since then the Westbury exposures have occupied a prominent position in accounts of British ferruginous deposits. At maximum, the workings extended for some 3.5 km along the strike to the north-east and south-west of Westbury (Figure 2.30), and an estimated two million tons of ore were extracted.

Both Blake and Hudleston (1877) and Woodward (1895) gave lengthy descriptions of the Westbury Ironstone Formation. Their accounts were followed, in the 1920s, by the works of Pringle (1922), White (1925) and Hallimond (1925). Mathews (1932) gave an invaluable account of the Westbury Ironstone as seen in the Westbury railway cutting, and Arkell (1934) provided a further, unfortunately very limited, description. He also monographed ammonites from the ironstone (Arkell, 1935–1948). In recent years the Westbury Ironstone Formation has figured prominently in the works of Wilson (1968a) and Talbot (1971, 1973a, b, 1974). Birkelund *et al.* (1983) briefly describe a borehole core through the complete formation.

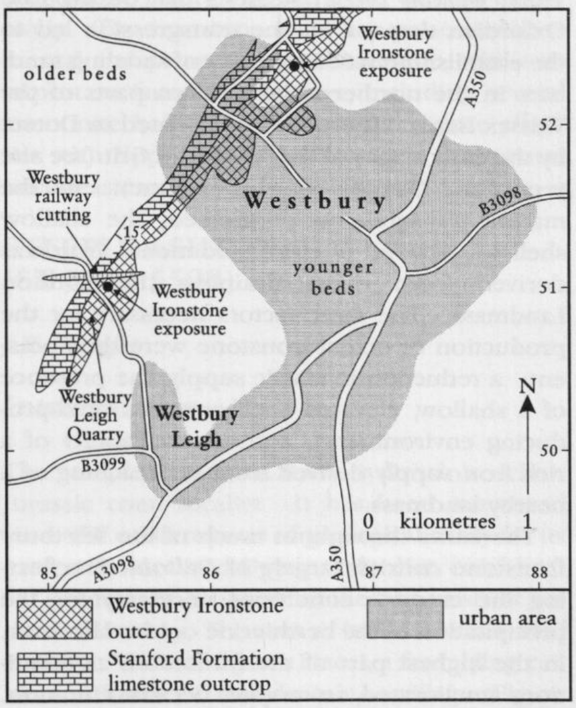

Figure 2.30 Locality map for sites around Westbury. Geological information from BGS Sheet 281 (Frome) (1965).

Despite the former importance of this deposit, and the extent of the workings, it has proved difficult to expose and conserve a safe section in the GCR site area, the former Westbury Leigh Quarry (ST 853 508); there remains only one small, incomplete section of the Westbury Iron Ore at (ST 8660 5245) (Talbot, 1974).

Description

The Westbury Ironstone is a localized deposit centred on Westbury, and extending to the south-west and north-east of the town (Figure 2.30). Arkell (1934) measured a thickness of 4.3 m in the Westbury railway cutting. A thickness of 4.6 m was recorded by R.W. Gallois in a nearby borehole (Birkelund *et al.*, 1983), north-east of the town. The typical facies recorded in the literature at all exposures comprises a highly ferruginous iron silicate oolite. Iron silicate ooids are normally formed initially of berthierine (Burkhalter, 1995), and are transformed to chamosite by diagenesis. X-ray diffraction methods are needed to distinguish berthierine from chamosite. Such work as has been done demonstrates that deeper burial in Britain has transformed berthierine to chamosite (Wright *et al.*, 2000). As 'chamosite' has become thoroughly established in the literature, use of this name is preferred here. The Westbury Ironstone contains variable percentages of limonite, siderite and chamosite. Mathews (1932) records the sideritic ore at the site as sufficiently iron-rich to yield up to 45% iron on smelting. Blake and Hudleston (1877) noted 38% to 42% Fe. The full range of rock types described from the Westbury Ironstone Formation comprises siderite–chamosite oolite, limonite oolite, siderite mudstone, and siderite–chamosite mudstone (Hallimond, 1925; Taylor, 1949).

Talbot (1974) described the one remaining exposure of the ironstone, a unique exposure consisting of pillars of ironstone left to support a minor road that runs across the former ironstone workings at (ST 8660 5245) (Figure 2.30). Although Talbot saw 4 m of ironstone, only 2.2 m are still visible. Soft, deeply weathered sideritic–chamosite oolite alternates with sideritic mudstone containing frequent *Deltoideum delta* (Smith). The oolitic beds, which predominate in the lower 2 m, contain densely packed ooids.

The Westbury Ironstone appears to be a transgressive deposit. The best opportunity for studying the relationship with the underlying beds would have been in the Westbury cement-works borings (Gallois in Birkelund *et al.*, 1983). However, the published log is of insufficient detail to be of use. In the area of Westbury town, Blake and Hudleston noted that beneath the ironstone was a persistent bed of light greenish-grey, brown weathering, clayey sand 1.2–3.1 m thick. This was underlain by compact, rubbly oolite (Calne Freestone). In an excavation at Westbury Leigh, 1.5 km to the south-west (ST 853 511) (Figure 2.30), the present author saw weathered limonite oolite resting directly on oolitic limestone, the ironstone having apparently overstepped the sand.

The disappearance of the Westbury Ironstone itself to the south-west of this exposure is due to overstep by early Cretaceous beds, but the disappearance of the ironstone north-east of Westbury is more puzzling. The ironstone is present to normal thickness beneath Westbury cement-works 1.5 km north-east of the town (Gallois in Birkelund *et al.*, 1983). Strata of this age are then faulted out, but 3 km to the north-east, only clayey sand was mapped by the Geological Survey, separating Corallian limestone from Ringstead or Kimmeridge Clay. A remnant of Westbury Ironstone may be present beneath Steeple Ashton church (see site report for Steeple Ashton, this volume). Overstep by either the Ringstead Clay or the Kimmeridge Clay is the most probable explanation.

The bulk of the fossils found in the ironstone came from the upper, sporadically oolitic mudstone (Mathews, 1932, Bed 3). Several species of *Ringsteadia* have been found, including the holotypes of *Ringsteadia pseudocordata* (Blake and Hudleston) and *R. anglica* Salfeld, together with *Perisphinctes (Perisphinctes) wartaeformis* Arkell (holotype), *Perisphinctes (Arisphinctes) westburyensis* Arkell (holotype), and *Microbiplices anglicus* Arkell. Mathews (1932) also recorded from this bed a bivalve assemblage dominated by the oyster *Deltoideum delta*, in association with *Pleuromya, Nanogyra* and *Trigonia*. Shell beds can occur anywhere in the succession, however, with a bivalve fauna dominated by *Deltoideum delta* and *Nanogyra nana* (J. Sowerby), while *Unicardium* sp. has also been recorded (Mathews, 1932; Arkell, 1934).

Interpretation

The Westbury Ironstone, as with many other iron-bearing sediments, is regarded as having accumulated in a shallow marine or near-shore environment (James, 1966; Curtis and Spears, 1968; Brookfield, 1973a; Talbot, 1974). Donaldson *et al.* (1999) suggest that ironstone formation is associated with the early stages of marine transgression. During such an event, clastic sediment is ponded in alluvial and coastal areas, and shelves are starved of sediment. Within bathymetrically elevated parts of the sea floor, precipitation of berthierine would take place within the sediment below the sea floor where there was abundant dissolved iron in pore water. Owing to the shallow conditions, ooids would be subject to alternating periods of physical reworking and shallow burial, producing the layered structure to the ooids.

Borehole evidence (Lamplugh *et al.*, 1920, 1923; Wilson, 1968a) suggests that during Late Oxfordian times, a marine transgression led to the establishment of a complex of shoaling sandbars in the northern and western parts of the Wessex Basin. These are represented in Dorset by the early stages of the Sandsfoot Grit (see site report for Osmington, this volume). As the marine transgression progressed, the shallow shelf was starved of clastic sediment. Iron was derived from rivers draining the London Landmass. The three factors necessary for the production of ooidal ironstone were thus present: a reduction in clastic supply, the presence of a shallow, elevated shelf area (an ooid-producing environment), and the availability of a rich iron supply derived from the leaching of a nearby landmass.

The fauna throughout much of the Westbury Ironstone consists largely of *Deltoidea*, reflecting the extreme conditions necessary for the precipitation of the berthierine ooids. However, in the highest part of the formation, as conditions ameliorated, ammonites became common. Arkell (1935–1948) emphasized the considerable stratigraphical importance of the ammonite assemblage collected from this site. The species of *Ringsteadia* found at Westbury, such as *R. pseudocordata* and *R. anglica*, and *Microbiplices anglicus* Arkell, bear close affinities with species found in the Sandsfoot Grit of Weymouth (see site report for Sandsfoot, this volume). Close correlation between these two units is certain. The clayey sand beneath the Westbury Ironstone appears to be the equivalent of the Red Down Ironsand of north-west Wiltshire (see site report for Steeple Ashton, this volume). It may be the equivalent in Dorset of the earliest Sandsfoot Grit, which is also argillaceous (see site report for Sandsfoot, this volume). The Westbury site is of importance in European palaeogeography and stratigraphy, as a similar fauna can be collected from the ironshot oolite of Hesdin l'Abbe, near Boulogne. However, it is the presence of *Perisphinctes* (*sensu stricto*) that is of greatest interest to continental workers, as this subgenus appears to have continued at Westbury after it had become extinct on the continent (Wright, 1998).

Conclusions

This is a site of national importance as the type locality for the Upper Oxfordian Westbury Ironstone, a ferruginous sedimentary iron ore of remarkable purity that was once worked extensively. The ironstone is of key palaeoenvironmental and palaeogeographical value, whilst its important faunal assemblage, including several ammonite holotypes, demonstrates close affinities with Upper Oxfordian faunas in Dorset and north-eastern France.

STEEPLE ASHTON (ST 9160 5598)

J.K. Wright

Introduction

The Steeple Ashton GCR site is Britain's richest Jurassic coral locality. It has been renowned since the earliest years of geological study for its extremely localized Upper Oxfordian coral bed. No permanent exposure of the bed exists at the time of writing. The area of interest is in a field *c.* 300 m WSW of 'Spiers Piece', a farm lying *c.* 1 km south-east of Steeple Ashton village (Figure 2.31). The bulk of the coral fauna has been collected from this field and a valuable temporary trench was excavated in 1975 (Negus and Beauvais, 1979) in order to establish the relationship of the corals and the general stratigraphy.

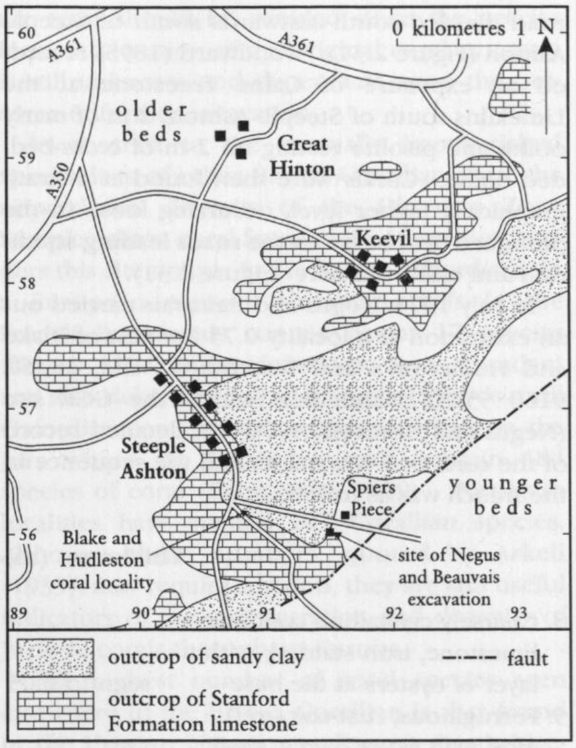

Figure 2.31 Locality map for the Steeple Ashton GCR site. Geological information from BGS Sheet 281 (Frome) (1965).

The site was described by Parkinson (1804–1811) and briefly mentioned by Lonsdale (1832, pp. 261, 263, 275). Corals from the locality were monographed by Milne-Edwards and Haime (1851) and the site described at length by both Blake and Hudleston (1877, pp. 286–7) and Woodward (1895, pp. 72, 111–12). More recently, authors such as Arkell (1928, 1933, 1935, 1935–1948), Negus (1975), and especially Negus and Beauvais (1979) have each emphasized the considerable stratigraphical, palaeogeographical and palaeoecological value of this site to Oxfordian geology.

Description

No actual exposure of the Steeple Ashton Coral Bed had ever been seen prior to the excavation carried out by Negus and Beauvais (1979). Blake and Hudleston (1877) noted that corals occurred in the field on the north side of the road that led south-eastwards south of Steeple Ashton (Figure 2.31). Woodward (1895) recorded an exposure of Calne Freestone at the Limekilns south of Steeple Ashton, 2 m of marly oolite and pisolite resting on 2 m of cross-bedded oolite. Corals were then found at a stratigraphically higher level, occurring loose in the ploughed field between the roads leading south-east and east from here (Figure 2.31).

In July 1975, Negus and Beauvais carried out an excavation at a locality 0.75 km east of Blake and Hudleston's and Woodward's site, at (ST 9160 5598), which falls within the GCR site (Negus and Beauvais, 1979). A detailed record of the coral bed was made, and the sequence in the trench was as follows:

	Thickness (m)
6. Coarsely crystalline coralline limestone, iron stained, with a layer of oysters at the base	seen to 0.05
5. Ferruginous, rust-coloured marl with many corals, shell fragments and much shell debris including *Nanogyra nana* (J. Sowerby) and serpulids	0.18
4. Rubbly, impersistent, pale-grey limestone with soft, marly patches and rare bivalves	at maximum 0.10
3. Grey, slightly rust-coloured marl, weathering cream-coloured	0.40
2. Irregular, rubbly, pale-grey limestone with rare bivalves	at maximum 0.10
1. Cream-coloured marl (hard limestone in base of trench)	0.20

A log of the section is given in Figure 2.32. This shows a thickness of at least 1.05 m of carbonates, with the scleractinian coral fauna restricted to Bed 5, a ferruginous marl deposit (Negus and Beauvais, 1979, fig. 1, p. 214). The coral colonies were observed to lie only 0.3 m below the field surface, a fact that readily accounts for such large numbers formerly being ploughed up so easily. The fine external preservation of the corals at the site has been noted by many authors, although the internal structure has been largely recrystallized, and a typical specimen shows replacement by sparry calcite or, to a lesser extent, micrite.

As was noted above, the Steeple Ashton Coral Bed is present in only a small area south-east of

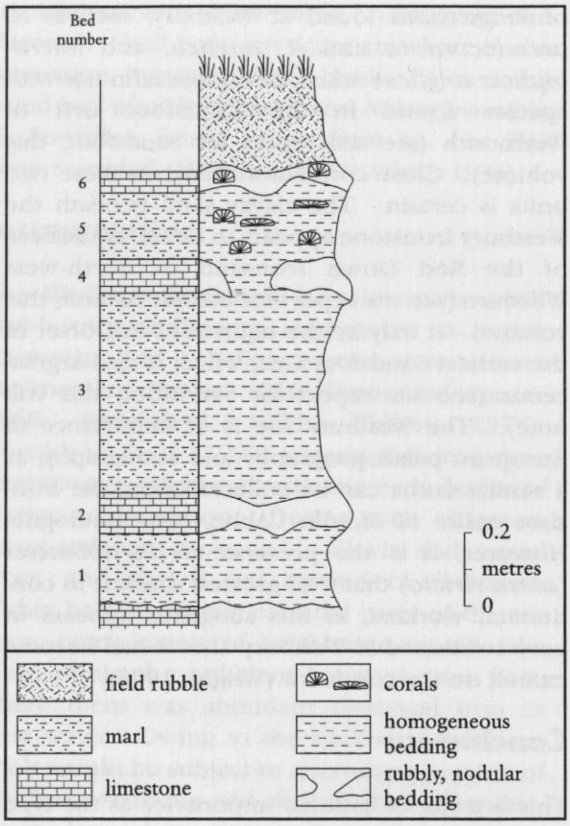

Figure 2.32 Log of the Corallian succession at Steeple Ashton (after Negus and Beauvais, 1979, fig. 1).

Steeple Ashton village, having apparently been removed by erosion over much of the area beneath overstepping sandy clay (Figure 2.31). This sandy clay was correlated with the ?Rosenkrantzi Zone Red Down Ironsand of north-west Wiltshire by Arkell (1951). Blake and Hudleston (1877) noted that the high ground around the village church was charged with red oxide of iron, and that iron ore was said to have been mined there. This may well be a thin representative of the Westbury Ironstone, coming in above the sandy clay as at Westbury (see site report for Westbury, this volume). Two oversteps seem to be involved, one beneath the sandy clay, restricting the outcrop of the coral bed to the area south-east of Steeple Ashton, and one beneath overstepping Ringstead Clay restricting the outcrop of the Westbury Ironstone to the area of Steeple Ashton itself. Stratigraphically, the horizon of the Steeple Ashton Coral Bed comes well above that of the

Coral Rag (Figure 2.2). Negus and Beauvais (1979) record *Amoeboceras* sp., of Late Oxfordian age.

From this locality, 46 scleractinian species belonging to 23 genera have been recorded. In this fauna, lamellar and fungoid forms are the most numerous, including the genera *Thamnasteria, Morphastraea, Mesomorpha, Protoseris, Fungiastraea, Thamnoseris, Microsolena* and *Comoseris.* No rounded massive forms occur, and only one phaceloid genus (*Calamophylliopsis*) is present. Solitary corals are represented by the genus *Montlivaltia*, which is abundant. Dendroid forms related to *Montlivaltia* (*Cladophyllia*, *Latiphyllia* and *Thecosmilia*) are also relatively numerous. Plocoid corals such as *Stylina, Cryptocoenia* and *Crateroseris* are quite rare. The full species list from the site, with new species, and systematic descriptions of the corals, is given by Negus and Beauvais (1979).

Associated with the corals is a facies-dependent reef-fauna consisting predominantly of attached and encrusting bivalves and serpulids. *Nanogyra nana* is common along with *Chlamys natheimensis* (de Loriol). *Gastrochaenolites* borings into *Thamnasteria concinna* (Goldfuss) contain natural casts of *Lithophaga inclusa* (Phillips). Serpulids occur on many of the Steeple Ashton corals and include tubes of the species *Mucroserpula tricarinata* (J. de C. Sowerby) and *Glomerula gordialis* (Schlotheim). *Myophorella clavellata* (Parkinson) burrowed into muds in between coral colonies. Negus and Beauvais (1979, p. 221) record a quite well-preserved rhynchonellid brachiopod, *Torquirhynchia* cf. *speciosa* (Münster), not previously recorded below the Kimmeridgian, from the site, whilst the echinoids *Acrosalenia angularis* (Agassiz) and *Nucleolites scutatus* Lamarck have been found here associated with cidarid spines.

Interpretation

The Steeple Ashton Coral Bed represents one of the youngest British Oxfordian coral developments. It post-dates the Coral Rag of north-west Wiltshire and Oxfordshire, the Upware Limestone in Cambridgeshire and the Yorkshire Coral Rag, all of Tenuiserratum Zone age (Wright, 1980). However, it pre-dates the Rosenkrantzi Zone Ringstead Coral Bed of south Dorset. Although Arkell referred to Steeple Ashton as a true reef, Negus and Beauvais (1979) advise that the term should be avoided since the precise form and location of the original coral structure is still unknown and dependent upon the outcome of further excavation.

In contrast to the normally impoverished species lists of other British Corallian sites, the unparalleled diversity of the Glosense Zone Steeple Ashton coral fauna, with 46 species, renders this site unique in the British Oxfordian. In a European context, Corallian reefs in the French Boulonnais contain about 17 species (Tomes, 1884) and reefs become more abundant and also richer in coral species southwards until Oxfordian coral growth reaches its acme in the Jura where the Rauracian reefs contain 184 species of coral (Koby, 1881–1889). Portugese localities have yielded 147 Corallian species. Although these numbers, quoted by Arkell (1935), may require revision, they are still useful indicators of the concentration and diversity of Jurassic corals throughout Europe.

The highest number of coral species seen elsewhere in the British Corallian is that found in the Upware Limestone of south Cambridgeshire, where nine scleractinian species are now known to occur (see site reports for Upware South Pit and Dimmock's Cote Quarry, this volume). The Coral Rag of southern England and of Yorkshire provides only six or seven species, at best, although the number of individuals is high, especially in Oxfordshire. The greater diversity of scleractinian species at Steeple Ashton is thus in marked contrast to the Coral Rag faunas of sites such as Dry Sandford Quarry (Cothill), Shellingford Crossroads Quarry and the other GCR sites in the vicinity of Oxford, all of which are characterized only by species of *Thecosmilia*, *Rhabdophyllia, Isastraea*, *Fungiastraea* and *Thamnasteria.*

Explanations for the paucity of coral species elsewhere in the English Corallian have to take into account the large number of species at Steeple Ashton. While latitude may have played some part in limited coral development and dispersal in the case of the faunally impoverished Oxfordian coral assemblages of Yorkshire (see site reports for Hackness Head and Betton Farm, this volume), latitude alone cannot have been the cause of the impoverishment of the Oxford fauna, situated relatively near to Steeple Ashton. It is difficult to agree with Arkell (1947b) that the difference in numbers of species between the British and European faunas was chiefly due to isolation from the main coral build-up in

Europe. Steeple Ashton, after all, was almost entirely isolated, the only other corals found in England at this horizon being small fragments of *Thamnasteria* recorded from the Dorset Clavellata Member (Arkell, 1935–1948). Salinity, water temperature, depth and turbulence due to current activity were probably the major features governing the 'selection' of the scleractinian assemblage that flourished at Steeple Ashton, suggesting unique environmental conditions in the vicinity.

The biological and morphological characteristics of the species in this assemblage give some clues as to the palaeoenvironment. Plocoid corals, known to adapt themselves to active sedimentation, are not numerous. The prevalence of thamnasteroid and cerioid forms seems to indicate both limpid water and gentle sedimentation, whilst the greater number of flat or fungioid colonies may indicate a soft bottom. No massive forms have been recorded here. The overall impression is one of a flourishing, very diverse coral assemblage in which many genera and species had the opportunity to develop in an offshore shelf area of variable depth. The morphology of the foliaceous colonies suggests that growth may have occurred along a vertical face. Negus and Beauvais (1979) suggest that the closest recent analogue is that referred to by Pichon (1972) as 'l'horizon des formes foliacées' or 'horizon intermediaire' which is located on the outer slope of the reef-front of the 'Grand Recif' of Tulear (Madagascar) at about 5–12 m deep. Here currents prevent any deposits smothering the corals, and foliaceous and encrusting forms prevail (see also Laporte, 1974). Insalaco (1996) noted that the presence of foliaceous forms is a good indicator of coral growth in relatively deep water.

Though they are not found in growth position, the preservation and concentration of the corals suggests that it is unlikely they were transported any great distance and were probably derived from the collapse and disintegration of some coral structure less than a kilometre from their position of burial. It has been suggested that the structure may lie *in situ* somewhere in the vicinity (B. Rosen, pers. comm., in Negus and Beauvais, 1979).

Arkell (1927) correlated the Steeple Ashton Coral Bed with the Clavellata Member of Dorset. The occurrence of a fragmentary *Amoeboceras* sp. collected from the field surface in association with the corals by Negus (Negus and Beauvais, 1979) supports this correlation, while a study of the ostracod fauna from the 1975 trench by T. Kilenyi confirms the Glosense Zone age of the fauna (Negus and Beauvais, 1979).

Conclusions

Steeple Ashton has long been renowned for its very localized coral bed which provides Britain's most valuable locality for the study of Jurassic corals. A total of 46 scleractinian species belonging to 23 genera have been recorded from the site, which produces a diverse assemblage list contrasting strongly with the normally impoverished coral assemblages of other British Corallian sites. The standard of preservation of the individuals and the concentration of the coral fauna within an extremely limited geographical area is unique in British Oxfordian stratigraphy. The Steeple Ashton coral fauna can be equated in its composition with the rich Middle and Upper Oxfordian zonal coral assemblages of the Jura, although it has few affinities with other sites in Europe. The coral bed is a key invertebrate locality bearing considerable stratigraphical, palaeogeographical and palaeoecological interest.

SEEND CLEEVE (ST 934 609)

J.K. Wright

Introduction

Seend Cleeve Quarry is one of the few remaining exposures of Corallian strata in the once heavily quarried Seend and Calne area of north-west Wiltshire (Figure 2.33). The locality was first described by Lonsdale (1832), and subsequently by Blake and Hudleston (1877) and Woodward (1895). However, it was not until the time of Arkell (1933, p. 393, 1935–1948, 1951, pp. 5, 6) that the full stratigraphical value of the Seend Cleeve succession was realized, and the Seend area became the type area of the Lower Oxfordian Cordatum Subzone. This site has played a prominent role in helping to re-evaluate the Lower and Middle Oxfordian stratigraphy of north-west Wiltshire (Wright, 1980). The quarry, 250 m across, is now grassed over and criss-crossed by public footpaths, but much of the quarry face is preserved.

Seend Cleeve

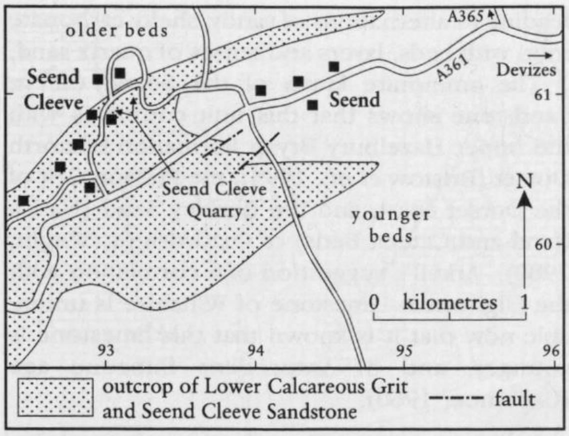

Figure 2.33 Locality map for the Seend Cleeve GCR site. Outcrop of the Corallian sandstones from BGS Sheet 281 (Frome) (1965).

Description

Accounts of the area prior to 1951 attributed all the sandstones of the Seend Cleeve area to the Lower Calcareous Grit. However, two distinct ammonite faunas were recorded from the area by Arkell (1935–1948), a Lower Oxfordian Cordatum Subzone fauna from the lower 12 m of typical Lower Calcareous Grit, and a Middle Oxfordian Vertebrale Subzone fauna from the shelly gritstone (Seend Cleeve Sandstone) at the top of the section.

No exposures remain of the Lower Calcareous Grit proper, but the shelly gritstone is exposed at several locations within the quarry. The quarry face yields limited exposures only, at the time of writing. In 1978, the following was seen by the present author at (ST 934 609):

	Thickness (m)
3. Flaggy, shelly, sandy limestone with numerous foraminifera seen in thin section, and with a distinctive, brown-weathering, micritic matrix. A thin band of medium-grained, calcareous sandstone is present at the top	seen to 1.15
2. Soft, medium-grained quartz sand with lens-shaped, fossiliferous concretions containing *Pleuromya uniformis* (J. Sowerby), poorly exposed	approx. 1.20
1. Coarse-grained, poorly sorted, sandy, shelly limestone, partially decalcified, with *Gervillella aviculoides* (J. Sowerby)	seen to 0.45

A weathering profile of the section is given in Figure 2.34. Beds 1 and 3 contain quartz grains and bivalves set in a micritic matrix. The quartz grains frequently exceed 1 mm in diameter. Quartz pebbles between 2 and 6 mm are common at the top of Bed 1. The quarry face has deteriorated somewhat since 1978, and at the time of writing the sandy limestone and sandstone of Bed 3 only are exposed. Beds 1–3 were formally named the Seend Cleeve Sandstone by Wright (1980).

The Lower Calcareous Grit was originally described by Lonsdale (1832). He saw a 7.5 m section exposed in a quarry at the foot of Seend Hill, on the south-east side of the Trowbridge Road. The predominant lithology was a fine-grained quartz sand, with irregular lenses and beds of intensely hard 'grit' (calcareous sandstone). The cemented beds were frequently very fossiliferous, sometimes so much so that the rock became an impure, shelly limestone. Woodward (1895) saw 3.6 m of white sand, with

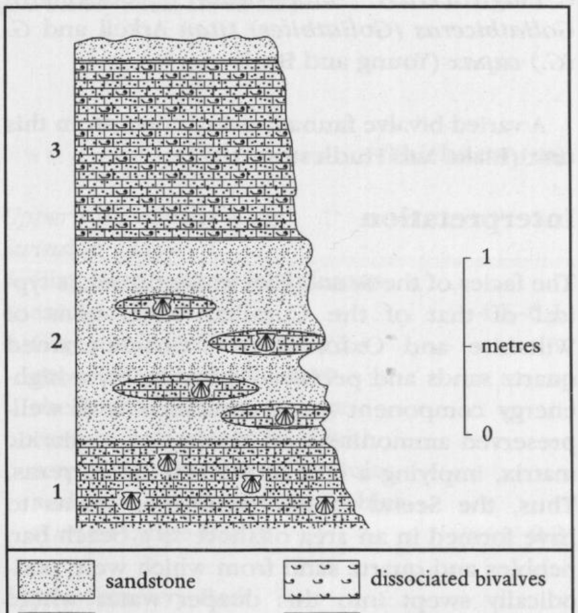

Figure 2.34 Weathering profile of the Corallian succession at Seend Cleeve Quarry as seen by J.K. Wright in 1978.

brown iron staining, and with seams of brown clay, exposed in a pit 'west of Seend Iron Works'. Some portions of the sand were shelly, with *Liostrea* sp., *Chlamys* sp. and *Nanogyra nana* (J. Sowerby), and irregular concretions were developed.

Both the Lower Calcareous Grit, which presumably was exposed in the floor of the present quarry, and the Seend Cleeve Sandstone, yielded numerous ammonites during the period when the quarries were being worked (Arkell, 1935–1948). The following are believed to have come from this quarry and from other now defunct quarries in the Seend Cleeve area:

Lower Calcareous Grit (Cordatum Subzone)
Cardioceras (Cardioceras) cordatum (J. Sowerby), *C. (C.) galeiferum* Buckman (holotype), *C. (C.) ashtonense* Arkell, *C.(Scoticardioceras) stella* Buckman (holotype), *(C.) (?Scarburgiceras)* sp., *Goliathiceras (Goliathites) cyclops* Arkell (holotype), *Aspidoceras (Euaspidoceras) nikitini* Borissjak, and *A. (E.) acuticostatum* (Young and Bird)

Seend Cleeve Sandstone (Vertebrale Subzone)
Cardioceras (Cardioceras) cordatiforme (Buckman), *C. (Vertebriceras)* cf. *dieneri* Neumann, *C. (Sagitticeras) moderatum* (Buckman), *Goliathiceras (Goliathites) titan* Arkell and *G. (G.) capax* (Young and Bird)

A varied bivalve fauna is also known from this unit (Blake and Hudleston, 1877).

Interpretation

The facies of the Seend Cleeve Sandstone is typical of that of the Corallian shell beds of Wiltshire and Oxfordshire. Coarse-grained quartz sands and pebbles – presumably a high-energy component – are combined with well-preserved ammonites and bivalves in a micritic matrix, implying a lack of winnowing currents. Thus, the Seend Cleeve Sandstone seems to have formed in an area offshore to a beach bar, pebbles and quartz sand from which were periodically swept into this deeper water where there were insufficient currents to wash away interstitial carbonate mud, and where the prolific fauna of bivalves and foraminifera could thrive. Periodically, severe storms swept more substantial amounts of quartz sand into the area, leading to alternations of sandy, shelly carbonate mud with beds, layers and lenses of quartz sand.

The ammonite fauna of the Seend Cleeve Sandstone shows that this unit correlates with the upper Hazelbury Bryan Formation of north Dorset (Bristow *et al.*, 1995), the Preston Grit of the Dorset coast, and the Beckley Sand (Natica Band and Catena Beds) of Oxfordshire (Wright, 1980). Arkell's suggestion of a correlation with the Highworth Limestone of Wiltshire is untenable now that it is known that this limestone is younger, and of Antecedens Subzone age (Callomon, 1960).

Conclusions

It is likely that this quarry has produced many of the excellently preserved cardioceratids of Cordatum Subzone age (see Arkell, 1935–1948, pl. LXVIII) recorded from the district, which is the type area for the Subzone. This is the stratotype section of the Seend Cleeve Sandstone, and is the only exposure of beds of Vertebrale Subzone age between Oxfordshire and the Dorset coast to yield a good ammonite fauna.

OLD TOWN, SWINDON (SU 153 832)

B.M. Cox

Introduction

The Kimmeridgian GCR site known as Old Town, Swindon comprises a cutting on the former Midland and South Western Junction Railway (M & SWJR) which was made on the south side of Old Swindon, Wiltshire in the 1890s (Figure 2.35).The *c.* 460 m long section, to the west of Swindon Town (Old Swindon) Railway Station and south of Westlecot Road bridge, was first recorded by Woodward (1895). It showed Upper Kimmeridge Clay in predominantly sandy facies, overlain by Portlandian sandy limestones and sands. The presence of sandy beds in the Upper Kimmeridge Clay is a peculiarity of the south and central Midlands as far north as Oxford (see also site report for Littleworth Brick Pit, this volume). At Swindon, the sandy beds were frequently exposed in the cemetery overlooking Clifton Street and, following Buckman (1923), they are called the 'Cemetery Beds'; many fine, uncrushed ammonites have been found in the material

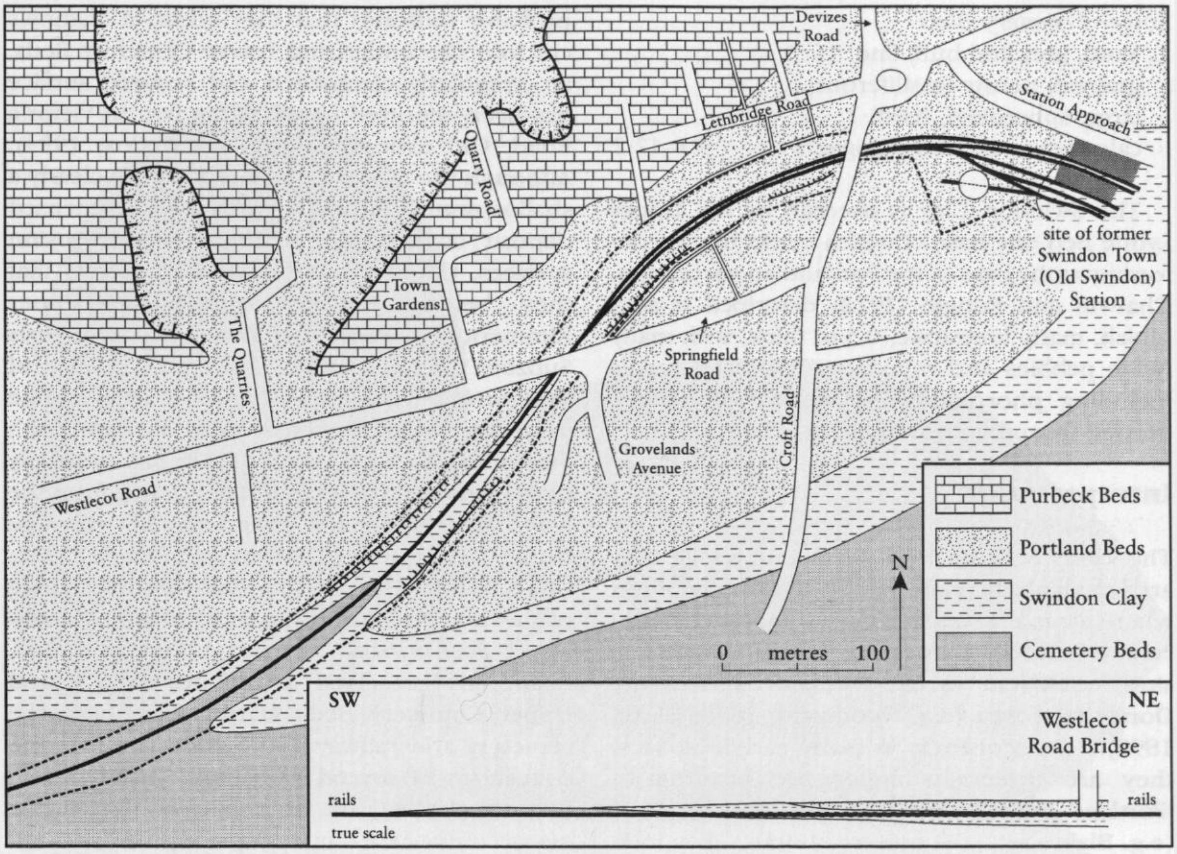

Figure 2.35 Sketch map of the cutting on the former Midland and South Western Junction Railway. The line is now dismantled. The section south-west of Westlecot Road bridge constitutes the Kimmeridgian GCR site. (Geology based on Arkell, 1948, fig. 1 and British Geological Survey Sheet SU 18 SE.)

thrown out during grave-digging (Chatwin and Pringle, 1922). The town gives its name to the Swindon Clay, which overlies the Cemetery Beds (or their lateral equivalents) in this region; this is the highest part of the Kimmeridge Clay Formation that is preserved at Swindon.

Description

The following section is based on that recorded by Woodward (1895), Chatwin and Pringle (1922) and Buckman (1922–1923); for ease of reference in the present account, bed numbers (1–5) have been added to their beds. A longitudinal section of the cutting was shown by Woodward (1895, fig. 99) and Arkell (1933, fig. 79) but Arkell's (1948) later section and plan are used as the basis of Figure 2.35. The railway is now dismantled and the old trackway is a designated cycle route.

	Thickness (m)
Upper Kimmeridge Clay	
Swindon Clay	
5. Clay, blue, poorly fossiliferous, sandy at base	4.3–6.1
4. Clay, marly and sandy, hard, greenish, glauconitic, very shelly with numerous large oysters (many encrusted with serpulids); phosphatic nodules and pebbles, and lydite pebbles (Lower Lydite Bed)	0.2
Upper Cemetery Beds	
3. Sands and clays with *Nanogyra nana* (J. Sowerby)	0.9–1.2
2. Sandstone, green and red, marly, highly glauconitic, very shelly, with tiny lydite pebbles	0.9–1.2

Lower Cemetery Beds

1. Sand, grey and buff, fine grained, poorly fossiliferous; large, spheroidal, hard, calcareous sandstone doggers	9.1–12.2

The Swindon Clay is overlain by the Upper Lydite Bed, the base of which marks the unconformity at the base of the Portlandian succession. Chatwin and Pringle (1922) described it as a bluish, marly limestone, 0.3 m thick, with many lydite pebbles and numerous reworked fossils including phosphatized pavloviid ammonites derived from the Swindon Clay.

Interpretation

The sandy beds in the Upper Kimmeridge Clay are particularly well developed at Swindon where for many years they were thought to represent the lower part of the Portlandian succession, equivalent to the Portland Sand of the Dorset type area (e.g. Woodward, 1888; Blake, 1892). Consequently, in many early accounts, they are discussed under the heading of 'Portland Beds' rather than 'Kimmeridge Clay' (e.g. Blake, 1880; Woodward, 1895). They indicate the availability of coarser material and suggest the proximity of land in Late Kimmeridgian times. Their zonal position was established by the palaeontological work of Salfeld (1913, 1914) whose results were subsequently amended and amplified by Chatwin and Pringle (1922) (Arkell, 1933). Chatwin and Pringle (1922) based their evaluation of the Swindon succession largely on a collection of fossils, many from the M & SWJR cutting, made by W.H. Hudleston, which was subsequently presented to the Geological Survey in 1920. The Portland Sand is, in fact, rather thinly developed at Swindon, being represented by only 1.5 m of glauconitic sandy limestone (Wimbledon, 1980). The subdivision of the Kimmeridgian sandy beds into Lower and Upper Cemetery Beds (Buckman, 1922–1923) is based on their contrasting lithologies. The upper unit is highly glauconitic and very shelly whereas the lower unit is dominated by soft sands that were sufficiently loose to be dug by hand in the upper pit of the former Hill's Brickyard (SU 140 837); in the BGS Swindon Borehole, they were washed away during drilling (Gallois and Cox, 1994).

The lateral thickness variation of the Upper Cemetery Beds over relatively short distances probably indicates that they occur in channels cut into the underlying Lower Cemetery Beds; an irregularly channelled and scoured surface has been reported between the two in Victoria Road, Old Swindon (Gallois and Cox, 1994). Although the Upper Cemetery Beds are clearly a shallow-water, intensely winnowed, condensed deposit containing numerous minor erosion surfaces, the ammonite evidence suggests that they belong entirely within the Upper Kimmeridgian Pectinatus Zone (Eastlecottensis Subzone) (Cope, 1978). The type specimen of *Pectinatites (P.) eastlecottensis* (Salfeld) came from the Upper Cemetery Beds at 'Eastlecott', Swindon, although Salfeld (1913) had originally but erroneously described it as coming from the lydite bed above the Swindon Clay (i.e. the Upper Lydite Bed) (Chatwin and Pringle, 1922; Cope, 1967). The characteristic very fine ribbing of this taxon makes it the most readily identifiable *Pectinatites* species (Figure 2.36). Beautifully preserved ammonites in a typical Upper Cemetery Beds matrix, from both the cemetery and railway cutting, are amongst the collections of several museums. According to Wignall (1990a), the abundant non-ammonite macrofauna of the Upper Cemetery Beds is dominated by cemented epifaunal forms although infaunal bivalves are also important; the rarity of free-lying epifaunal forms may reflect unstable, shifting substrate conditions. Assigned to his 'B7 *Cycloserpula intestinalis–Nanogyra nana* Association', Wignall (1990a) reported the serpulid *Cycloserpula intestinalis* (Phillips) and the bivalves *Nanogyra nana* (J. Sowerby), *Myophorella voltzii* (Agassiz), *Camptonectes auritus* (Schlotheim) and *Nicaniella cuneata* (J. Sowerby) as the most common taxa. *Nanogyra nana* (*Exogyra bruntrutana* (Thurmann) in the early literature) is sufficiently abundant that the beds have been referred to as the 'Exogyra nana Bed(s)' or 'Exogyra Bed(s)' (Woodward, 1895; Arkell, 1933, 1947b; Cope 1978, 1980).

In contrast, the fauna of the Lower Cemetery Beds is poorly known but generally believed to be sparse, although there may be sufficient fossil specimens in museum collections for the age of these beds to be determined (Gallois and Cox, 1994). A limited bivalve fauna has been reported from the sandstone doggers (Blake, 1880). Woodward's (1895) extensive faunal list, based largely on Blake (1880), is misleading as it actually relates to the lowest part of the Upper Cemetery Beds. The age of the Lower Cemetery

Figure 2.36 The type specimen of *Pectinatites* (*P.*) *eastlecottensis* (Salfeld) as figured by Salfeld (1913) but enlarged to natural size.

Beds is therefore not proven although, on the basis of data from the BGS Swindon Borehole, Gallois and Cox (1994) suggested that they belonged to the Upper Kimmeridgian Wheatleyensis and Hudlestoni zones but probably no higher, given that the base of the Upper Cemetery Beds appears to mark a substantial erosional hiatus; at least part of the underlying Scitulus Zone is developed in 'normal' clay facies.

The presence at Swindon of indigenous *Pavlovia pallasioides* (Neaverson) in the Swindon Clay indicates that it belongs to the Upper Kimmeridgian Pallasioides Zone and that it correlates with part of the thick sequence of relatively uniform calcareous mudstones that underlie the Rotunda Nodule Bed in the cliffs adjacent to Chapman's Pool, Dorset (Cope, 1978; Gallois and Cox, 1994). The erosional 'gap' between the Swindon Clay and overlying Portland Beds at Swindon corresponds with about 80 m of calcareous mudstones, silty mudstones and muddy siltstones (the beds above the Rotunda Nodule Bed) in Dorset (Chatwin and Pringle, 1922; Gallois, 2000; see site report for Tyneham Cap–Hounstout, this volume).

Conclusions

In the 19th century, some of the best exposures of Kimmeridge Clay in the country were to be seen at and near Swindon where several large brickpits and cuttings, made during the construction of the railway network of which Old Swindon became the centre, exposed the formation (Arkell, 1947b). In this area, as elsewhere in the south and central Midlands (see site report for Littleworth Brick Pit, this volume), the Upper Kimmeridge Clay includes units of sand that are not seen in the formation's type section on the Dorset coast or elsewhere in Britain. Fossils, particularly ammonites, are much better preserved in these sandy lithologies than in the equivalent clay beds of the type section, and many museums contain fine specimens of ammonites collected from the Upper Kimmeridgian Pectinatus Zone of Swindon. Extensive fossil collections were made during construction of the old Midland and South Western Junction Railway to the south of Old Swindon in the 1890s including the now-abandoned cutting that comprises the GCR site. These enabled the Upper Jurassic succession at Swindon to be finally resolved. The cutting provides a reference section (in its type area) for the ammonite *Pectinatites (P.) eastlecottensis* (Salfeld), which gives its name to the Eastlecottensis Subzone of the Pectinatus Zone, as well as for the Swindon Clay, the youngest member of the Kimmeridge Clay Formation here, which is recognized as a separate entity as far north-east as Aylesbury (see site report for Littleworth Brick Pit, this volume). The Lower and Upper Lydite beds which represent pauses in deposition are also well developed, the latter marking the hiatus with local erosion that preceded limestone deposition in Portlandian times.

SHELLINGFORD CROSSROADS (SU 326 942)

J.K. Wright

Introduction

Shellingford Crossroads Quarry lies 22 km WSW of Oxford (Figure 2.37). It first came into prominence when Treacher (1907) led a Geologists' Association excursion in the Faringdon area during which the site was visited. The first detailed descriptions of the Shellingford sequence were those published by Arkell (1927, 1939a, 1947b). Arkell also monographed bivalves from this quarry (Arkell, 1929–1937). Callomon (1960) largely confirmed Arkell's stratigraphy of the area, with only slight amendments. The exposure figures prominently in the accounts of Wilson (1968a) and Talbot (1973a) on Corallian carbonate sedimentology and event stratigraphy.

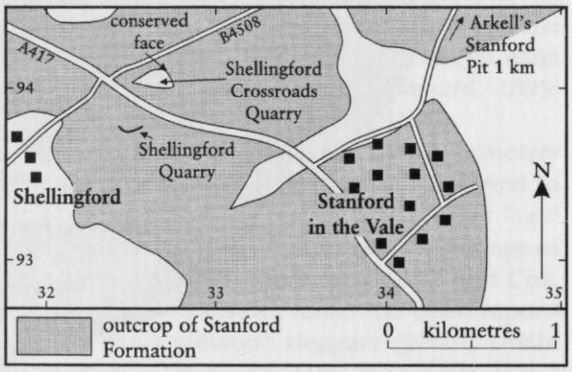

Figure 2.37 Locality map for the Shellingford Crossroads GCR site. Outcrop of the Stanford Formation (mapped as 'Corallian limestone g11b') from BGS Sheet 253 (Abingdon) (1971).

A further description of the section is given by McKerrow and Kennedy (1973), while the locality also figures prominently in the works of Fürsich (1974, 1975), Ali (1977), Wright (1980), Johnson (1983) and Goldring *et al.* (1998b).

The area of interest in Shellingford Crossroads Quarry comprises a conserved portion of the quarry face where an ESE–WNW-trending section, some 100 m in length, exposes Middle Oxfordian rocks belonging to the Maltonense–Tenuiserratum Subzone interval. The site is particularly significant for its illustration of the complexities of Corallian stratigraphy in south-west Oxfordshire. Although part of the face was recently obscured during an operation to make it more safe, it showed the best section currently available through the highly variable lithologies of the Highworth Grit–Coral Rag interval.

Shellingford Crossroads Quarry is not to be confused with Shellingford Quarry (Goldring *et al.*, 1998b), situated south-west of the A417 (Figure 2.37). In an attempt to avoid confusing the two names, Goldring *et al.* (1998b) refer to Shellingford Crossroads Quarry as 'Stanford Quarry'. Unfortunately this introduces further potential confusion as an important section in the Corallian beds, described by Arkell (1947b), was formerly visible in a pit near Stanford, the latter naturally being referred to by Arkell as 'Stanford Pit'.

Description

The following section, compiled from measurements by the author and by Goldring *et al.* (1998b), has been visible at Shellingford Crossroads Quarry. The Highworth Grit and Faringdon Members are now largely obscured within the area of the conserved face, though the Highworth Grit is accessible elsewhere in the quarry.

	Thickness (m)
Stanford Formation	
Coral Rag Member	
9. Micritic limestone containing massive colonies of *Thamnasteria concinna* (Goldfuss) and *Isastraea explanata* (Goldfuss)	seen to 0.45
8. Bioclastic limestone with moulds of *Thecosmilia annularis* (Fleming), both rolled and in growth position	0.6
7. *Stanford Oncolite Bed*: muddy oncolite infilling ?scour channels	0–0.25
– erosion surface –	
Faringdon Member	
6. Tough, bioclastic oolite containing small bivalves and gastropods, and with occasional quartz pebbles	0.45
5. *Urchin Marl Bed*: Rubbly oolite, medium to coarse grained, containing *Nucleolites scutatus* Lamarck. An irregular junction is present on to harder oolite below. No erosion surface is visible, however	0.72
4. *Third Trigonia Bed*: thick-bedded oolite, weathering flaggy, with frequent dissociated bivalves, especially *Gervillella aviculoides* (J. Sowerby) and comminuted shells towards the base	0.89
3. *Pebble Bed*: limestone with pebbles of many kinds of limestone and shale and sandstone, the clasts frequently reaching several centimetres in size, and with small quartz pebbles	0.53
– extensively bored erosion surface –	
Kingston Formation	
Highworth Grit Member	
2. Perry facies: oncolitic and oolitic sands, muds and sandy oosparite with an erosional base marked by *Diplocraterium parallelum* Torell	0–1.80
1. Shellingford facies: fine-grained, cross-bedded sand, ripple drift bedding brought out by clay laminae, and with clay drapes towards the top	seen to 5.0

A general log of the section after Goldring *et al.* (1998b) is given in Figure 2.38. These authors provide a detailed description of the Highworth Grit, which they subdivide into two members. However, as the Highworth Grit is regarded herein as a member of the Highworth Formation, it cannot be subdivided into members, and the new subdivisions are treated here as informal facies subdivisions of the Highworth Grit Member.

The limestone sequence is allocated to a new Stanford Formation, this being the type section,

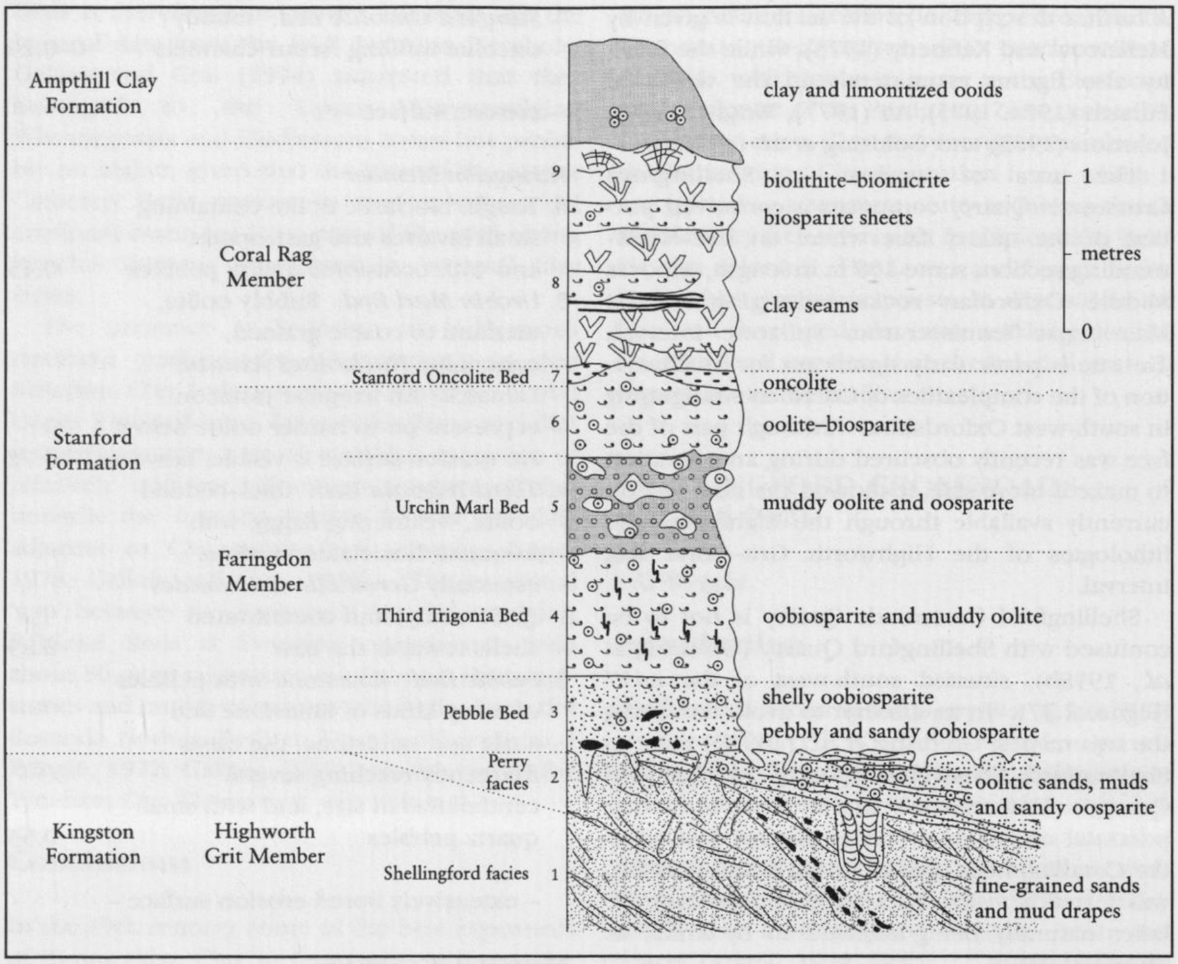

Figure 2.38 Log of the Corallian succession at Shellingford Crossroads Quarry (after Goldring *et al.*, 1998b, fig. 3).

divided into Faringdon and Coral Rag members. Goldring *et al.* (1998b) referred the predominantly oolite succession at the site (beds 3 to 6, Figure 2.38) to the Osmington Oolite Formation, but as this oolite succession is treated herein as a member of the Stanford Formation, 'Osmington Oolite' is not appropriate, and the term 'Faringdon Member' is re-introduced, having been rejected initially by Wright (1980). 'Faringdon Oolite' was a term first used by Arkell (1939a), sometimes as a facies term, and Shellingford Crossroads Quarry was included in the definition of the facies. Though Shellingford Crossroads Quarry is the type section, excellent cores through the member were recovered from the base of Wicklesham Quarry, Faringdon (Goldring *et al.*, 1998b). Various subdivisions of this oolite succession were made by Arkell (1939a) and Callomon (1960). These are included as bed subdivisions within the Faringdon Member.

The 'Coral Rag' (beds 7 to 9) is regarded herein as the uppermost member of the Stanford Formation, and not as a formation itself, as used by Goldring *et al.* (1998b). Goldring *et al.*'s 'Stanford Member', which is only 0.25 m thick at maximum, becomes the 'Stanford Oncolite Bed'. *Thecosmilia* was the initial colonizer upon the oncolite surface. The phaceloid branches of this coral have now been dissolved out, leaving moulds of the corals preserved in a biomicrite that is rich in *Rhaxella* spicules. There were several erosive events truncating coral growth (Ali, 1977), enabling scattered colonies of *Thamnasteria* and *Isastraea* to grow upon the hardground surfaces.

Ammonites collected from the locality are usually poorly preserved, Arkell (1935–1948) recording *Perisphinctes (Dichotomosphinctes) antecedens* Salfeld and *P. (Arisphinctes) pickeringius* (Young and Bird) from Bed 3 (?uppermost Maltonense Subzone) as well as *Cardioceras (Scoticardioceras) excavatum* (J. Sowerby).

Interpretation

The Shellingford facies of the Highworth Grit is seen at present on the west side of Shellingford Crossroads Quarry and in Shellingford Quarry at (SU 327 938). With its small channels, cross- and ripple-drift bedding, clay drapes and clay-pebble conglomerates, it exhibits the varied energy regimes characteristic of tidal deposition (Johnson, 1983), or of estuarine or delta distributary (Goldring *et al*. 1998b). Bipolar dips in the cross-stratification indicate a channel flowing towards the south-east. The point-bar facies is truncated by two major erosion surfaces introducing the wedge of fine sands, oncoidal and ooidal sands and muds of the Perry facies. This was formerly exposed in the conserved face, but is, at the time of writing, obscured. The basal surface of this ooidal facies bears the features (planation and colonization by the *Diplocraterion*-producing animal) of a transgressive surface, with a rapid transgression in an estuarine environment (Goldring *et al*., 1998b).

The almost planar base of the Faringdon Member Pebble Bed (Bed 3) cuts evenly across both underlying facies of the Highworth Grit. Chert pebbles and fish teeth are present in the Pebble Bed. The Third Trigonia Bed (Bed 4) is a high-energy, predominantly *Gervillella* shell bed, and is typical of the *Gervillella aviculoides* association of Fürsich (1977), an association typical of high-energy conditions. The oriented, dissociated valves suggest combined wave and current activity. Scattered *Myophorella* valves occur in addition, swept in from the more offshore environment preferred by this burrowing bivalve.

Bed 4, the Third Trigonia Bed, was correlated with the Upper Trigonia Bed of the area south-west of Oxford by Arkell (1947b). Callomon (1960) noted that, coming above the Highworth Grit, Bed 4 could not correlate with the Upper Trigonia Bed, which comes beneath the Highworth Grit at Lamb and Flag Inn Quarry (Figure 2.41). Therefore Bed 4 should be termed the 'Third Trigonia Bed'. Its facies is really a variant of the standard Corallian ooidal facies. The ooidal limestone and marl subdivisions of the Faringdon Member are best interpreted as 'lagoonal', back-barrier sediments with the barrier inferred to lie to the south (Goldring *et al*., 1998b). The presence of fine quartz sand as cores in the ooids indicates that sand was entering the depositional area, probably from reworking of the Highworth Grit. As was pointed out by Goldring *et al.* (1998b), Bed 5, the Urchin Marl, is of local significance, and these authors also believe that the *Trigonia* shell beds considered by Arkell (1947b) to represent correlatable horizons across Oxfordshire must be regarded as localized.

The basal unit of the Coral Rag is now recognized to be the Stanford Oncolite Bed (Bed 7) (Goldring *et al.* 1998b). At Shellingford Crossroads Quarry, a complex unit of oncolite-filled scour structures up to 0.25 m deep and 1.0 m wide occurs beneath the coralliferous sediments. This unit marks a significant stratigraphical event. At the base there is an erosion surface and at the top a firmground with the initiation of coral colonization. The coralliferous beds have been the subject of detailed petrographical and palaeoenvironmental analysis by Wilson (1968a) and Talbot (1973b). They are formed of rubbly, bioclastic limestone containing principally autochthonous branching *Thecosmilia* with associated massive *Thamnasteria* and *Isastraea*. Branched coral colonies are most common in the lower part of the section (Bed 8), whilst in the upper part (Bed 9) massive forms prevail. It was noted by Ali (1977) that the growth of *Thecosmilia* at this locality had been interrupted at three principal horizons by deposition of lenses of biosparite and by argillaceous sediment that had smothered the corals. Determination by X-ray diffraction of the mineralogy of the clay fraction has shown that it is 60–70% smectite. This suggests strongly that the clay seams interbedded with the corals are the result of alteration of contemporary volcanic material.

Chowdhurry (1982) noted that smectite is present throughout the Corallian succession in this region, with peaks in the Lower Calcareous Grit and Coral Rag. Zeolites are also present, plus unweathered biotite and apatite. The most likely origin for these four minerals was from contemporary volcanic ash, delivered directly to the site of deposition as air-fall sediments.

Broad peaks spread over several metres of strata suggest repeated ash falls from a volcano situated to the south-west, and redistribution of the volcanic ash by marine currents in the shallow shelf.

The section has received considerable attention from stratigraphers, and provided one of the major pieces of evidence for the hypothesis of correlation by event stratigraphy in the Oxfordian (Talbot, 1973a). Talbot was impressed with the similarity of the junction of the Faringdon Member oolite on Highworth Grit at Shellingford Crossroads Quarry and that of the Osmington Oolite on Bencliff Grit at Osmington. Both sections show impure, pebbly oolite resting on, and infilling borings in, cross-bedded, marginally marine sandstone. In fact, the resemblance is only superficial. Ammonite evidence shows that the equivalent of the Highworth Grit in south Dorset is not the Bencliff Grit, but is probably the sandy Upton Member of the Osmington Oolite. The Faringdon Member oolite is represented only by the overlying, cross-cutting, Shortlake Member of the full Osmington succession (Wright, 1986a).

Conclusions

Shellingford Crossroads Quarry contains an outstanding section in Corallian rocks. The Highworth Grit shows trace fossils and sedimentary structures laid down in an estuarine environment. The Faringdon Oolite has at its base a pebble bed marking a significant and widespread regional non-sequence. This is overlain by shelly oolites containing a variety of bivalves and echinoids of great significance in palaeoecological studies. The Coral Rag is well known for its abundant in-situ corals and reef-dwelling bivalves. Shellingford Crossroads Quarry is thus of great importance for its illustration of the complexities of Oxfordian stratigraphy in the Oxford area.

LAMB AND FLAG (SU 381 974)

J.K. Wright

Introduction

Lamb and Flag Inn Quarry lies about 2 km WSW of Kingston Bagpuize, Oxfordshire (Figure 2.39), and about 16 km WSW of Oxford. Since first reported by Hull and Whittaker (1861), the quarry has occupied a prominent position in the literature on the Middle Oxfordian successions of southern England. Most of the area of the quarry is now given over to growing crops, but a small face 30 m long on the northern side of the quarry with an exposure of the Upper Trigonia Bed is conserved (Figure 2.39).

Blake and Hudleston (1877) gave a detailed description of the site, which is the type locality of their Corallian '*Trigonia*-bed', regarded at the time as a unique horizon traceable across Oxfordshire. The description was later reiterated by Woodward (1895). Pringle (1926) and Arkell (in Buckman, 1923–1925, pp. 57–9) and Arkell (1927) described the section in more detail, further information and conclusions being added subsequently (Arkell, 1939a, 1947b). The bivalve and ammonite faunas from the quarry were monographed by Arkell (1929–1937, 1935–1948). Since Arkell's time, the exact stratigraphical position of some of the beds that he described has been the subject of debate (Callomon, 1960; Wright, 1980; Johnson, 1983).

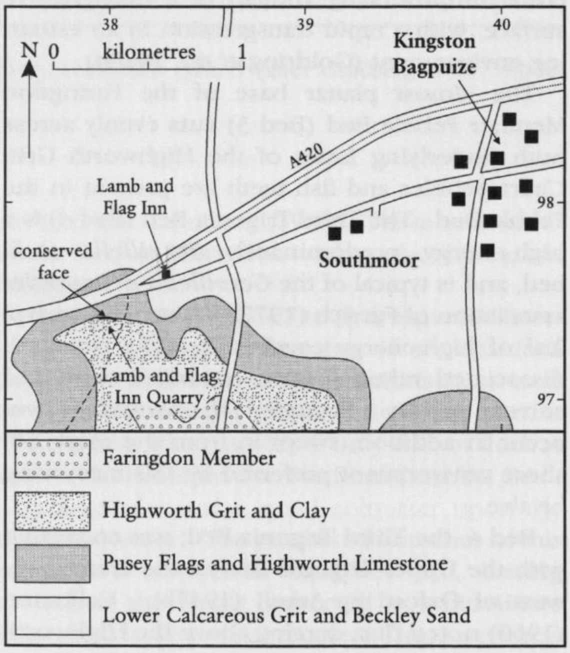

Figure 2.39 Locality map for the Lamb and Flag Inn Quarry. Corallian outcrops from Arkell (1939a, plate 30).

Description

The following is a complete section of the strata that have been exposed in the quarry. It is basically the section of Arkell (1927) updated by later observations made by Arkell (1947b) and by the present author in 1983, when the exposure was more complete than it is now. Information in brackets is taken from Arkell (1927).

	Thickness (m)
Kingston Formation	
Highworth Grit Member	
(11. Fissile sandstone with white ooids	0.3)
(10. Yellow sand with ooidal rubbly seams	1.2)
Highworth Clay Member	
(9. Brown clay	1.2)
– erosion surface –	
Highworth Limestone Member	
(8. *Urchin Marl*: white oolite, weathering flaggy	0.35)
(7. Grey, non-ooidal marl, full of broken shells	0.10)
6. *Upper Trigonia Bed*: tough, flaggy, sandy bioclastic limestone with frequent dissociated *Myophorella* sp., *Gervillella* sp., *Chlamys* sp., *Nanogyra nana* (J. Sowerby) and *Serpula* sp.	0.63
(5. Marl with *Perisphinctes* and bivalves	0.07)
(4. Impersistent band of *Gervillella* casts	0–0.15)
3b. *Pebble Bed = ?Lower Trigonia Bed*: sandy, pisolitic, ooidal, occasionally pebbly marl. Numerous bivalves present, especially *Nanogyra nana* and *Chlamys* sp.. Less quartz than 3a, but no real change in lithology	0.77
3a. Very sandy, medium-grained, shelly ooidal limestone. Well cemented and very pebbly at the base, with clasts of chert and fine-grained, calcareous sandstone	0.57
Lower Calcareous Grit Formation	
(2. Indurated sandstone	0–0.45)
(1. Yellow sand with occasional doggers	seen to 1.5)

A weathering profile of the section as seen in 1983 is given in Figure 2.40. Beds 3a, 3b and 6 were well exposed and fossiliferous at the time, but only Bed 6 is presently exposed.

The ammonite fauna collected from this quarry is very rich and diverse (Arkell, 1935–1948, pp. 392–3). Callomon (1960), using Arkell's collections, recognized three ammonite faunas:

Bed 6, Antecedens Subzone

Perisphinctes (Arisphinctes) spp. and *P. (Kranosphinctes)* spp. main stream (9 spp.)
P. (Liosphinctes) apolipon (Buckman)
P. (L.) aff. *linki* Choffat
Cardioceras (Maltoniceras) maltonense (Young and Bird)

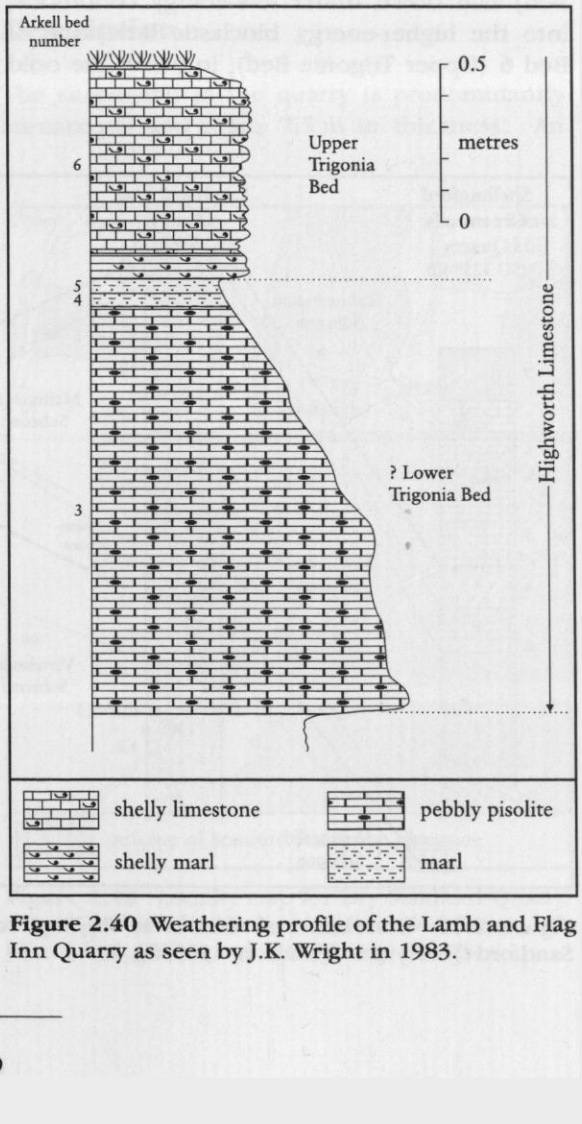

Figure 2.40 Weathering profile of the Lamb and Flag Inn Quarry as seen by J.K. Wright in 1983.

C. (Subvertebriceras) cf. *dieneri* Neumann
Beds 4 + 5
Perisphinctes main stream (2 spp.)
Bed 3, Vertebrale Subzone
Perisphinctes main stream (4 spp.)
Cardioceras (1 sp.)
Goliathiceras (1 sp.)
Aspidoceras (1 sp.)

Associated with the ammonites at this locality is a well-preserved, varied bivalve fauna (Arkell, 1929–1937).

Interpretation

Beds 3 to 8 form a continuous limestone sequence 2.5 m thick, and mark a lateral transition between the condensed shell beds of the Oxford and Cothill areas, and the Highworth Limestone of Wiltshire. Arkell did in fact refer to beds 3 to 8 as 'Highworth Limestone'. There is a marked change in lithology from the micritic, oncoidal limestone of Bed 3 (?Lower Trigonia Bed) laid down under low-energy conditions, into the higher-energy, bioclastic limestone of Bed 6 (Upper Trigonia Bed), in which the ooid and oncoid content is minimal. Both limestones are very fossiliferous, and must have accumulated very slowly. The majority of the faunas that occur here are environmentally diagnostic, providing fine evidence for the warm, shallow marine nature of the environmental regime prevailing during the Mid Oxfordian of southern England (Fürsich, 1974, 1975, 1976b, 1977).

The use of 'Lower Trigonia Bed' and 'Upper Trigonia Bed' above follows Callomon (1960) rather than Arkell (1947b). Arkell had applied the term 'Lower Trigonia Bed' to Bed 6, coming in as it did beneath the Highworth Grit. He used 'Upper Trigonia Bed' for the shell bed occurring above the Highworth Grit at Shellingford Crossroads Quarry (Bed 4 at Shellingford Crossroads GCR site, this volume). When Arkell saw two Trigonia beds in one section (beds 6 and 8 at Dry Sandford Quarry – see Dry Sandford GCR site report, this volume), he naturally used the names 'Lower' and 'Upper Trigonia Beds'.

Unfortunately, the Lower and Upper Trigonia Beds at Dry Sandford were subsequently shown to be of Vertebrale and Antecedens Subzone ages respectively (Callomon, 1960). As Bed 6 at Lamb and Flag Quarry was dated as Antecedens

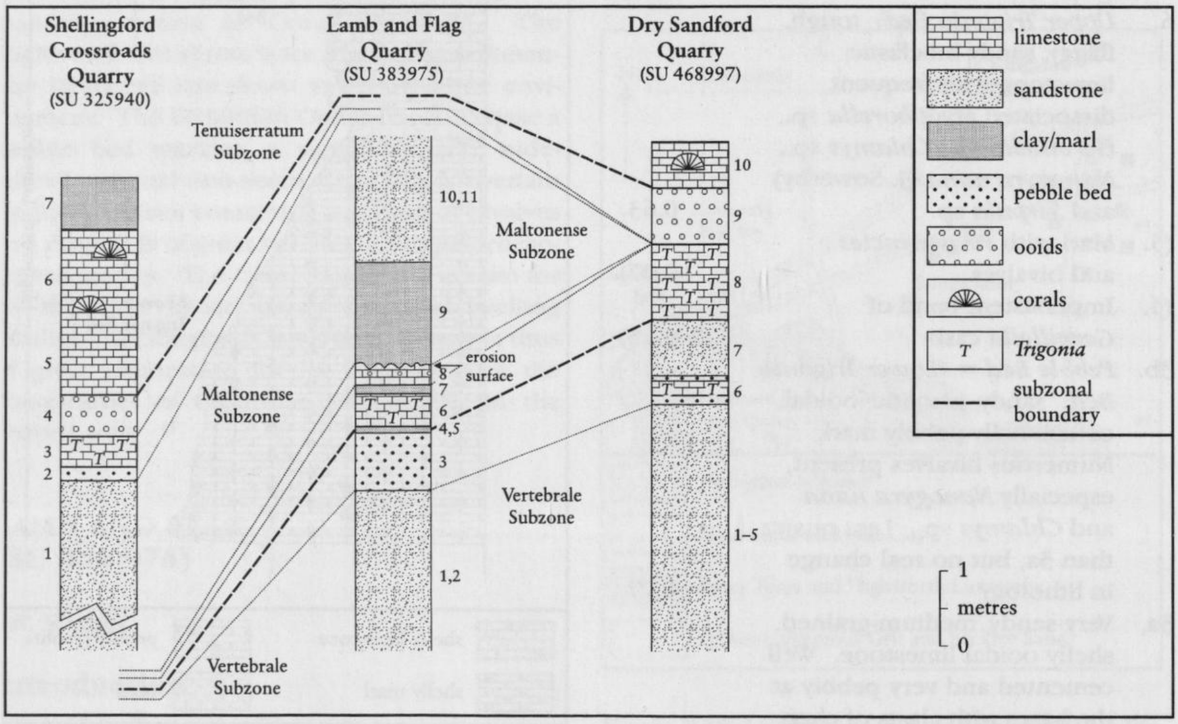

Figure 2.41 Correlation of sections at Shellingford Crossroads Quarry, Lamb and Flag Quarry, and Dry Sandford Quarry (after Johnson, 1983, fig. 2).

Subzone (= Maltonense Subzone) in age, it could not be the Lower Trigonia Bed, but must be the Upper Trigonia Bed. Yet it occurred beneath the Highworth Grit. The shell bed occurring above the Highworth Grit at Shellingford must be a Third Trigonia Bed. This correlation is set out in Figure 2.41. Bed 3 at Lamb and Flag Quarry probably represents the true Lower Trigonia Bed (Callomon, 1960).

On this interpretation, the Upper Trigonia Bed at Dry Sandford Quarry (this volume, Figure 2.42) should have been succeeded by the Pusey Flags, Highworth Clay, Highworth Grit and Third Trigonia Bed. All these are present in the Shellingford–Lamb and Flag area, but all are missing at Dry Sandford. This is presumably due to erosion or non-deposition. Johnson (1983) did not accept this conclusion, and claimed there were only two Trigonia beds, and that the missing beds at Dry Sandford were represented by Bed 7, coming in between the two Trigonia beds. This is only possible if one rejects the evidence of Callomon (1960) as to the age of the Lamb and Flag Trigonia bed (Bed 6) as revealed by its ammonite content. Neither of Johnson's proposals are accepted here: the ammonite evidence at Lamb and Flag Inn Quarry is as conclusive as it can be, and the lithology of Bed 7 at Dry Sandford is not that of the Highworth Grit, but is typical of the shelly, medium-coarse grained sands of the Beckley Sands.

Conclusions

The Lamb and Flag Inn Quarry includes an important section through the Trigonia beds of the Kingston Formation, and is the only section currently available exposing beds allocated to the Highworth Limestone Member. This site is noteworthy for its rich and well-preserved ammonite and bivalve faunas which have proved invaluable in stratigraphical, palaeogeographical and palaeoecological analyses of the complex Wiltshire–Oxfordshire Corallian outcrops.

DRY SANDFORD (SU 468 996)

J.K. Wright

Introduction

Dry Sandford Quarry lies within a nature reserve immediately south-east of the village of Cothill (Figure 2.42). Arkell (1936b, 1947b) referred to this quarry as 'Dry Sandford Quarry', but as Dry Sandford lies almost 1 km to the north, this can cause confusion, and 'Cothill' is usually given in the full title. This is a well-documented locality that, as a newly opened exposure, was first officially visited by geologists in 1930 (Arkell, 1933). The 150 m long preserved quarry face currently represents the best available section in the district for the examination of Middle Oxfordian strata below the Coral Rag.

Since its earliest documentation, the site has figured strongly in accounts of the Oxfordian Stage in southern England, being particularly well known through the works of Arkell (1936b, 1947b, 1935–1948). Callomon (1960) has produced a definitive account, and the sequence has also been described by McKerrow and Baden Powell (1953), McKerrow (1958) and McKerrow and Kennedy (1973). Talbot (1971) discussed the carbonate cements, and Talbot (1973a) and Johnson (1983) discussed the erosion surfaces and palaeoenvironment.

Description

The succession in the quarry is predominantly arenaceous and totals 7.5 m in thickness. An

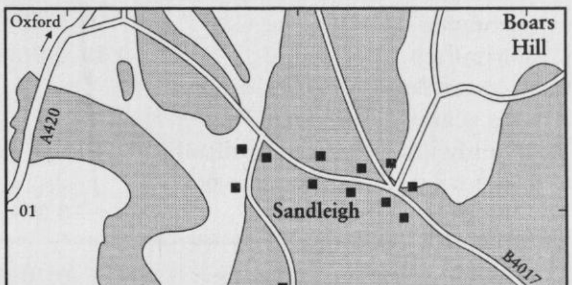

Figure 2.42 Locality map for Dry Sandford Quarry. Outcrop of Stanford Formation from BGS Sheets 253 (Abingdon) (1971) and 236 (Witney) (1982).

updated section is as follows (bed numbers and data on beds no longer exposed (in brackets) taken from Arkell (1936b)).

Thickness (m)

Stanford Formation

Coral Rag Member

10b. Flaggy, micritic limestone containing *Thecosmilia annularis* (Fleming) and *Thamnasteria concinna* (Goldfuss) in a fine-grained, slightly shelly matrix — seen to 0.25

10a. Tough, flaggy, bioclastic limestone containing well-preserved large bivalves in a bioclastic matrix with many coral fragments — 0.30

Kingston Formation

Beckley Sand Member

9. Soft, calcareous, fine- to medium-grained sand — approx. 1.0

8c. *Upper Trigonia Bed*: shelly, calcareous sandstone passing up into extremely sandy, shelly bioclastic limestone — 0.40

8b. Poorly cemented sand — 0.10

8a. *Upper Trigonia Bed*: shelly, medium-grained, very sandy limestone with only scattered, abraded shell fragments — 0.50–0.60

7. Iron-rich, shelly sand — 0.40–0.80

6. *Lower Trigonia Bed*: medium- to coarse-grained, shelly, very sandy limestone, sporadically ooidal, with well-preserved bivalves — 0.20

5. Poorly sorted, fine- to medium-grained, shelly sandstone — 0.70

(4. Gritstone, poorly fossiliferous — 0–0.45)

(3. Interlaminated shelly sand and clay — 0.15–0.30)

2. Sand with large calcareous concretions containing *Nanogyra nana* (J.Sowerby) and *Lima* sp. — 1.50

(1. *Natica Band*: extremely fossiliferous, decalcified gritstone — 1.55)

(seam of clay, underlain by white sand)

A log of the section as seen by Johnson (1983) is given in Figure 2.43. The nomenclature is not that of Johnson, however, as, following Horton

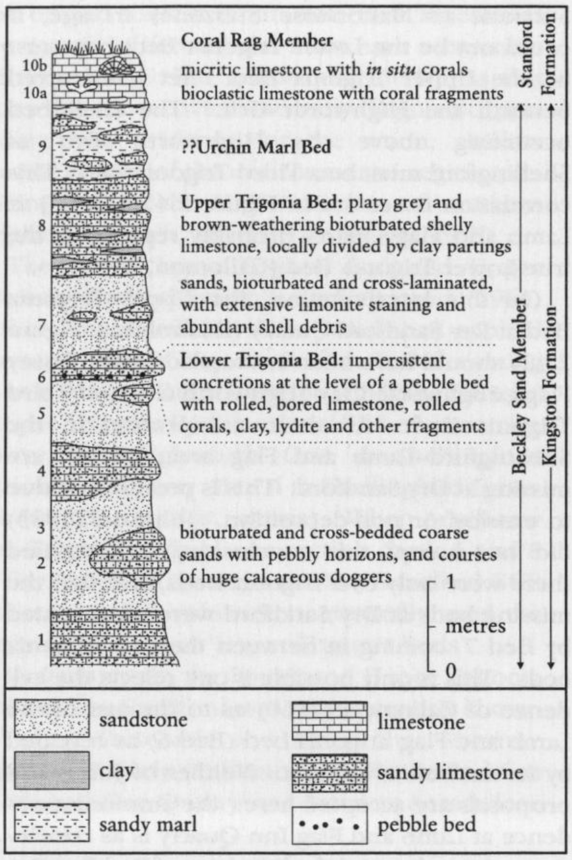

Figure 2.43 Log of the Corallian succession at Dry Sandford Quarry (after Johnson, 1983, fig. 1B).

et al. (1995), all the medium- to coarse-grained sands and sandy limestones lying between the fine-grained Temple Cowley Member (formerly Lower Calcareous Grit (pars)) and the Coral Rag are placed in the Beckley Sand Member. Arkell (1936b) recorded many corals in both beds 6 and 8, along with a large number of bivalve species. However, it is the remarkable number of ammonites collected here that gives the quarry its chief interest. Callomon (1960) lists 41 species of ammonite from Dry Sandford Quarry. The numbers of perisphinctid, cardioceratid and *Aspidoceras* species found in each bed are as follows:

Bed 8: 6 *Perisphinctes* spp., 1 *Cardioceras* sp., 1 *Goliathiceras* sp.

Bed 7: ?3 *Perisphinctes* spp., 5 *Cardioceras* spp., 3 *Goliathiceras* spp.

Bed 6: 6 *Perisphinctes* spp., 3 *Cardioceras* spp., 3 *Goliathiceras* spp., 2 *Aspidoceras* spp.

Bed 5: 3 *Perisphinctes* spp., 3 *Cardioceras* spp., 1 *Goliathiceras* sp., 4 *Aspidoceras* spp.
Bed 4: 2 *Cardioceras* spp.
Beds 3, 2: 2 *Cardioceras* spp., 2 *Goliathiceras* spp., 2 *Aspidoceras* spp.
Bed 1: 1 *Aspidoceras*. sp.

The fauna of Bed 8, with its great preponderance of perisphinctids, indicates the Antecedens Subzone of the Sub-Boreal Province, whereas the faunas of beds 1 to 7 are typical of the Vertebrale Subzone.

The Coral Rag, which here represents the Stanford Formation, is poorly exposed at the top of the quarry.

Interpretation

The soft sands in the lower part of the Beckley Sand Member with concretions up to 0.6 m thick and 1–2 m in diameter (Bed 2) are still well exposed. These coarse, shelly, cross-bedded sands with numerous bivalves and ammonites suggest rapid accumulation in a beach environment. The underlying Natica Band, a decalcified gritstone largely composed of the casts of the eponymous gastropod, is unfortunately no longer exposed. It is an excellent marker horizon traceable locally over several kilometres at the base of the Vertebrale Subzone.

The sequence in the upper part of the Beckley Sand Member consists of alternations of very sandy, shelly limestones with medium- or even coarse-grained, slightly shelly sands (Figure 2.44). Remarkably, all previous descriptions of this quarry (Arkell, 1936b; Callomon, 1960; McKerrow, 1958; Johnson, 1983) have failed to note the extremely sandy nature of the Trigonia Bed limestones (beds 6 and 8). These are so distinctive, and so markedly different in facies from that of the Highworth Formation limestones seen to the west, that they are included here within the Beckley Sand Member of the Kingston Formation. The danger of attempting to correlate these condensed, pebbly shell beds on lithology alone over even short distances is illustrated by Arkell's attempted correlation of Bed 6 at Dry Sandford with Bed 6 at Lamb and Flag Inn

Figure 2.44 View of the main north–south face at Dry Sandford Quarry, showing the Lower Trigonia Bed (Bed 6) and Upper Trigonia Bed (Bed 8) separated by shelly sand (Bed 7) marked by the hammer (shaft length, 30 cm). (Photo: J.K. Wright.)

Quarry. These were both labelled the 'Shell-Pebble Bed', and Arkell regarded them as equivalent. Callomon (1960) showed the ammonite faunas of these two beds to be very different, Bed 6 at Dry Sandford belonging to the Vertebrale Subzone, and Bed 6 at Lamb and Flag Inn Quarry to the Antecedens Subzone. Bed 8 at Dry Sandford, with its excellent Antecedens Subzone fauna, almost certainly correlates with Bed 6 at Lamb and Flag Inn Quarry (see Figure 2.41).

The difference in age of these two shell beds at Dry Sandford, separated by only 1 m of quartz sand (Figure 2.43, Bed 7), shows the slow nature of sedimentation in the area, or, given the coarse-grained nature of the sediment, the likelihood of marked gaps in the succession. Bed 7 forms a natural part of this sequence of alternations of poorly cemented sands and very sandy, shelly limestones. Johnson (1983) regarded Bed 7 as representing the Highworth Grit Member. However, the lithology of this bed is unlike that of this member at Shellingford Crossroads Quarry or Lamb and Flag Inn Quarry, and this interpretation is not accepted here. There is a marked change in facies from fine- to medium-grained quartz sand into non-sandy, bioclastic limestone at the base of the Coral Rag (Bed 10a) and, following Arkell and Callomon, it is accepted here that any representative of the Highworth Grit lay originally in this gap and has been removed by erosion. As was pointed out by McKerrow (1958), Bed 9 comprises a poorly cemented quartz sand. Arkell (1936b) noticed layers of sandy oolite in this bed, and suggested that it was equivalent to the Urchin Marl Bed, or possibly even part of the Highworth Grit.

As is often the case, the Coral Rag forms a transgressive sequence, consisting of bioclastic, coral-fragment sand laid down in shallow water, overlain by coral-rich micritic limestone. These cemented lime-mud deposits were laid down under quiet, stable lagoonal conditions, away from the marginal reef of the Oxford area, with the growth of both phaceloid or branching corals (*Thecosmilia*) and massive, encrusting corals (*Fungiastraea* and *Thamnasteria*).

Ammonite assemblages collected in the quarry have enabled substantial correlation to be achieved between the different Oxfordian faunal provinces. Ammonite faunas from this site represent both the Boreal and Sub-Boreal populations (see Chapter 1, 'Oxfordian and Kimmeridgian zones and subzones', and Figure 1.4), and have thus permitted important reassessment of ammonite zonations in Europe (Callomon, 1960; Sykes and Callomon, 1979). In addition, the faunal succession here was used by these authors to define the Plicatilis Zone of the Sub-Boreal Province, with its Vertebrale and Antecedens Subzones. The Vertebrale Subzone is recognized by the preponderance of *Cardioceras* and *Goliathiceras*, with *Aspidoceras*. In the Antecedens Subzone, *Perisphinctes* is by far the most common ammonite. The Antecedens Subzone is approximately equivalent to the Boreal Maltonense Subzone, its upper boundary probably extending above the base of the Boreal Tenuiserratum Zone (Sykes and Callomon, 1979). The subzones can only be defined in an exposure such as this where ammonite faunas are prolific.

Conclusions

This site is the most important of those described by Arkell (1936b, 1947b) and Callomon (1960) in their establishment of the sequence of ammonite faunas in the Middle Oxfordian of the Oxford District. The abundance of stratigraphically useful ammonites at Dry Sandford Quarry, Cothill, led to this being defined as the formal standard succession for the Plicatilis Zone by Callomon (1960). Though it is no longer possible to collect ammonites, the excellence of the exposure coupled with a detailed knowledge of the ammonite faunas makes the site invaluable in any study of Oxfordian stratigraphy, palaeogeography, or palaeoecology.

CUMNOR (SP 462 033)

J.K. Wright

Introduction

Bradley Farm Quarry (also known as 'Rockley Quarry', and situated close to Spring Farm, Cumnor; see Figure 2.45) has been worked from the late 1870s (Blake and Hudleston, 1877) up to at least 1947 (Arkell, 1947b). Early descriptions of the site were made by Hudleston (1880), Woodward (1895) and Pringle (1926). Arkell (1927, 1931) described the site in detail, and subsequently monographed bivalves (Arkell, 1929–37) and ammonites (Arkell, 1935–1948)

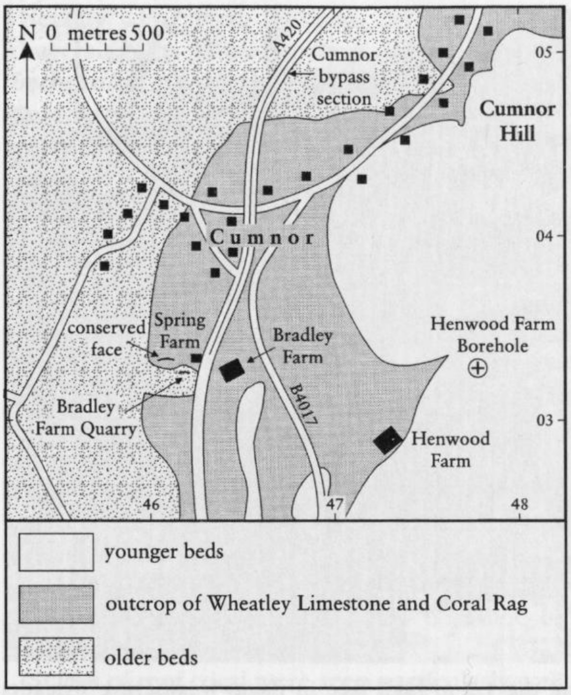

Figure 2.45 Locality map for the Cumnor GCR site. Outcrop of Wheatley Limestone and Coral Rag from BGS Sheet 236 (Witney) (1982).

from this locality.

A revised description was later published (Arkell, 1947b). At the time of writing, the area of the former quarry is largely made over to grassland, but a small 50 m long face in the upper part of the sequence is preserved along the northern boundary of the old quarry (Figure 2.46).

Description

When fully exposed, an 8.5 m succession of sandstones and limestones was visible at the quarry. Only Bed 6 was available for inspection by the author in 1998, and for description of beds 1 to 5 it is necessary to rely on the account of Arkell (1947b). Arkell's descriptions are in brackets.

	Thickness (m)
Stanford Formation	
Wheatley Limestone Member	
6. Tough, medium-bedded, flaggy weathering, bioclastic limestone consisting of a mass of coral and bivalve fragments in a sparry matrix. Less well cemented at the base	seen to 1.2
Kingston Formation	
Beckley Sand Member	
(5. *Shell–Pebble Bed*: shelly limestone with a pebbly base. Contains many bivalves, including *Myophorella hudlestoni* (Lycett), *Astarte ovata* Smith and *Gervillella aviculoides* (J. Sowerby), with *Cardioceras* spp.	0.15–0.56)
(4. Interlaminated sand and clay or even-bedded loam	0.69–1.20)
(3. Interlaminated loam, sand and clay containing mudstone concretions with *Nanogyra nana* (J. Sowerby) and *Natica* sp.	0.20)
(2. *Natica Band*: hard gritstone with a mass of *Natica* casts at the base	0.9–1.8)
(1. Yellow, cross-bedded sand with seams of clay, and with pebbles of quartz and chert	seen to 2.7)

Most of the interest of the quarry to earlier workers lay in the fossiliferous beds 2 and 5, not exposed at the time of writing. Arkell (1927) recorded 11 species of gastropod from Bed 2. The following ammonites have been recorded from this quarry (Arkell, 1935–1948). All are indicative of the Vertebrale Subzone:

Bed 5: *Cardioceras (Cardioceras) cuneiforme* Arkell (holotype)
Goliathiceras (Goliathites) titan Arkell (holotype)
Cardioceras (Scotcardioceras) excavatum (J. Sowerby)
Cardioceras (Cardioceras) cordatiforme (Buckman)
C. (Subvertebriceras) sowerbyi Arkell
C. (S.) densiplicatum Boden

Bed 2: *C. (S.) costulosum* (Buckman)
Goliathiceras (G.) capax (Young and Bird)
Aspidoceras (Euaspidoceras) catena (J. Sowerby)
Perisphinctes (Arisphinctes) cotovui Simionescu

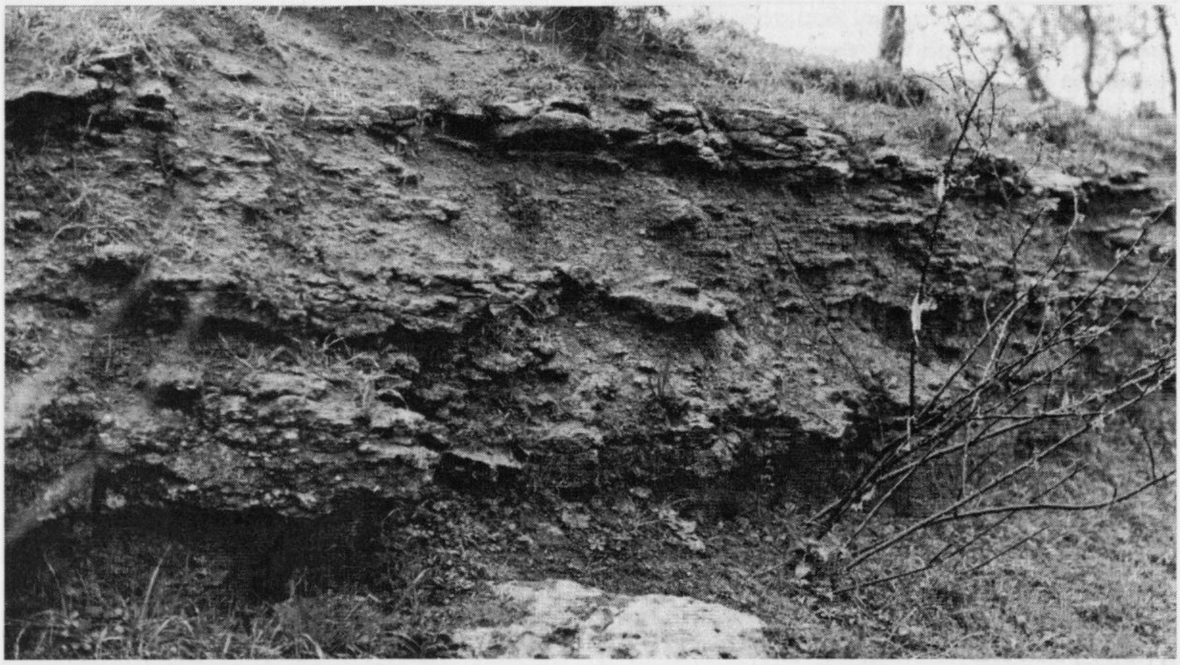

Figure 2.46 View of the Cumnor site in 1998, showing the 1.2 m high face in flaggy-weathering Wheatley Limestone. (Photo: J.K. Wright.)

P. (Liosphinctes) cumnorensis Arkell (holotype)

Only a limited thickness of Wheatley Limestone is preserved at present (Figure 2.46), and the lateral transition into Coral Rag, seen by Arkell (1947b) at the north-east corner of the quarry, is no longer visible.

Interpretation

The exposure was quarried largely for the sands of Bed 1. This showed marked cross-bedding; more so than that which occurs at the same stratigraphical horizon at Dry Sandford Quarry (see site report, this volume). This characteristic indicates greater shoaling of the sands in the Cumnor district and closer proximity to the 'Oxford Axis' (see below).

The earliest evidence of settled shallow marine conditions in the area is witnessed here by the most north-easterly known outcrop of the Natica Band, representing one of the earliest occurrences of a richly shelly bed in the Oxfordian of southern England. The bed is of great palaeogeographical interest, representing the atypical development of large, localized gastropod banks with clastic sedimentation reduced to a minimum.

Bed 5 has yielded only cardioceratids, and although these are not entirely zonally diagnostic, the absence of perisphinctids makes it almost certain that this is the Lower Trigonia Bed, of Vertebrale Subzone age. The higher condensed shell beds with their predominantly perisphinctid faunas of Antecedens Subzone age (Upper Trigonia Bed of Dry Sandford, Third Trigonia Bed of Shellingford Crossroads Quarry, and the Cowley–Sandford Shell Beds of the area south-east of Oxford) are not represented here.

Arkell (1933) used the term 'Oxford Axis' for this area of retarded Middle Oxfordian sedimentation, which extends from Cumnor east to Wheatley. Later, Arkell (1947b) abandoned the term 'Oxford Axis' and current thinking now places the Oxford area at the junction of the Birmingham–Oxford Block with the London Platform. The Birmingham–Oxford Block (the concealed Midlands Microcraton of BGS, 1996) is underlain by Palaeozoic rocks quite close to the surface, and was an area of reduced sedimentation during much of the Mesozoic Period (Horton *et al.*, 1995).

When fully exposed, the site was renowned for its display of the rapid facies changes that have been observed between Coral Rag and

Wheatley Limestone (Wilson, 1968a). Reef corals such as *Thamnasteria, Isastraea* and *Thecosmilia*, predominantly in growth position, could formerly be observed in the north-east corner of the quarry (Arkell, 1947b), and the site figures in Arkell's palaeogeographical distribution map of the reefs and channels of the Cumnor district (Arkell, 1935, pp. 83–9). Arkell (1947b, fig. 12) summarized this work, producing a map of the distribution of coral reef rock (Coral Rag) and reef debris (Wheatley Limestone) in the area between Dry Sandford Quarry and Cumnor. He showed that this was an area of patch reef, with the Wheatley Limestone occupying sinuous channels 100 to 300 m wide separating larger areas of Coral Rag 1 to 2 km across. He was struck by the extraordinary resemblance between the sections exposing Coral Rag and the low cliffs cut in Recent and Pleistocene raised reefs along the coastline of the Red Sea.

Stacks of reef coral were seen particularly well during the construction of the nearby Cumnor Bypass in 1981. Though the sections are beginning to grass over, there is still a considerable amount of exposure of the Coral Rag, and its lateral transition into Wheatley Limestone, in the bypass section.

Conclusions

A rich ammonite fauna has been collected from this quarry, especially from the Natica Band and condensed Shell–Pebble Bed. A total of seven ammonite species of the genera *Perisphinctes*, *Aspidoceras, Goliathiceras* and *Cardioceras* have been recorded, including the Middle Oxfordian zonal index *Cardioceras densiplicatum* and the holotypes of three species.

LITTLEMORE RAILWAY CUTTING (SP 532 028)

J.K. Wright

Introduction

Littlemore Railway Cutting lies 0.7 km west of Littlemore Station, where it is crossed by the A423. The cutting was mentioned briefly by Blake and Hudleston (1877), and was first described in detail by Cobbold (1880). Woodward (1895) and Pringle (in Buckman, 1923–1925, pp. 61–2) each gave detailed accounts of the succession. Arkell (1927) was the first to name the argillaceous parts of this sequence the 'Littlemore Clay Beds'. Further descriptions of the cutting followed (Arkell, 1933, 1947b). McKerrow and Baden Powell (1953) also described the locality briefly, as did Fürsich (1973). Callomon (1960) examined all ammonites collected from the cutting and gave a definitive list of species present. Wilson (1968a) discussed the environment of deposition of these beds. Horton *et al.* (1995) gave a thorough description illustrated by photographs of the sections as they were when first cut.

Description

The beds in the cutting dip slightly to the west (Pringle, 1926, pl. IIIB; Horton *et al.*, 1995, pls 7, 8), and are presently buried beneath a façade of loose talus and undergrowth. The description below is thus based on those of Arkell (1947b) and Pringle (in Buckman, 1923–1925, pp. 61–2), as modified by Horton *et al.* (1995), but using Pringle's bed numbers.

		Thickness (m)
Stanford Formation		
Littlemore Clay Member		
8.–27.	Alternating bands of blue-grey clay and nodular, white weathering mudstone or argillaceous limestone, in layers a few centimetres thick	5.0
7.	Shelly limestone with *Perisphinctes (Perisphinctes)* sp.	0.6
Kingston Formation		
Beckley Sand Member		
6.	Buff, shelly sand, crowded with dwarf *Chlamys fibrosus* (J. Sowerby) and *Nanogyra nana* (J. Sowerby)	0.25–0.3
5.	Brownish-grey, marly limestone	0.15–0.3
4.	Brown, shelly sand with *Chlamys fibrosus* resting on an irregular surface of Bed 3	0.35
3.	*Littlemore Shell Bed*: dark grey, gritty limestone containing many ammonites. At the base is a shelly layer with small pebbles of chert and quartzite	approx. 0.3
2.	Dark grey, calcareous sandstone	0–0.25
1.	Buff sands, with spherical and elongated calcareous concretions on three levels	seen to 4.5

The shallow marine sands at the base, once regarded as part of the Lower Calcareous Grit, are now taken, together with beds 3–6, as the equivalent of the Beckley Sand (Wright, 1980). Bed 3 is the highly fossiliferous Littlemore Shell Bed. Beds 7 to 27 can conveniently be grouped as the Littlemore Clay Member. Fourteen ammonite species have been identified from this cutting (Callomon, 1960). The vast bulk of the fauna occurs in Bed 3, which is clearly a condensed deposit. Owing to the importance of these ammonite records in correlating the Littlemore sequence, the full faunal list as published by Callomon (1960) is given below:

Littlemore Clay Member
- Beds 21, 27
  - *Perisphinctes (Dichotomosphinctes) buckmani* Arkell
- Bed 15
  - *P. (? Kranaosphinctes)* sp.

Beckley Sand Member
- Bed 7
  - *P. (Perisphinctes)* sp.
- Bed 3 (Littlemore Shell Bed)
  - *P. (Dichotomosphinctes) rotoides* Ronchadzé
  - *P. (Arisphinctes)* cf. *cotovui* Simionescu
  - *P. (A.) pickeringius* (Young and Bird)
  - *P. (A.) helenae* de Riaz
  - *P. (Kranaosphinctes)* cf. *trifidus* (J. Sowerby)
  - *P. (K.) cymatophorous* (Buckman)
  - *P. (K.) decurrens* (Buckman)
  - *Cardioceras (Subvertebriceras) densiplicatum* Boden
  - *C. (Vertebriceras)* cf. *vertebrale* (J. Sowerby)
  - *C. (Scoticardioceras)* sp.
  - *Goliathiceras* cf. *chamoussetiforme* Arkell

The fauna of Bed 3 is clearly that of the Vertebrale Subzone; the sandy beds 4 to 7 may belong to the Antecedens Subzone, while the higher beds belong to the Parandieri Subzone.

Interpretation

The Littlemore Shell Bed represents a fine example of a remanié deposit laid down during a period of intense sediment starvation and is one of a number of such deposits occurring in the highly attenuated Middle Oxfordian succession in Oxfordshire, where deposition was controlled by the Birmingham–Oxford Block, the principal tectonic structure of the region (Horton *et al.*, 1995) (see site report for Cumnor, this volume). The Shell Bed has a pebbly base indicating an erosive contact with the underlying strata, and derived ammonites suggest a considerable stratigraphical break with the overstep of this horizon onto progressively older rocks.

The site is best known as the stratotype section of the Littlemore Clay Member, a predominantly argillaceous equivalent of the Coral Rag and Wheatley Limestone, developed under relatively low-energy conditions. The lithologies comprise interbedded clays and limestones. The outcrop is restricted to a belt 2–3 km wide running ESE–WNW along the Thames Valley for a distance of at least 10 km. At the only other exposure in similar facies (Hillmarton, North Hinksey), Arkell (1947b) recorded interbedding of coralliferous with argillaceous lithologies, and suggested that inhibition of coral growth may have been due to blanketing with clay (see also Wilson, 1968a).

Following Cobbold (1880), Arkell (1927) suggested that the clay of the Littlemore Clay Member was derived from rivers flowing from the south-east off the London Platform. However, borehole evidence, according to Wilson (1968a), shows that coralliferous limestone facies extends in this south-easterly direction, and that it is more likely that the terrigenous clay was derived from the north-west. The channel through the coral reef facies in which the clay is thought to have been deposited has characteristics similar to modern tidal channels traversing the coral reefs of the Trucial Coast.

The transition from the normal reef-dominated carbonate sequences of the Oxford district to the clay-rich Littlemore Clay Member is reflected in the nature of the latter's bivalve fauna. This provides a typical example of a soft-sediment infauna (Arkell, 1927; Fürsich, 1976b). *Astarte* sp., *Isocyprina* sp. and *Pholadomya* sp. occur together with the ubiquitous *Nanogyra nana*. Such forms provide extremely useful environmental indicators, being tolerant of the terrigenous influxes that characterize the member.

Conclusions

The site is an important locality in any study of Jurassic sedimentation and facies change. The Littlemore Member, the argillaceous equivalent of the Coral Rag–Wheatley Limestone succession, comprises a clastic-dominated sequence of impure limestone and clay units laid down in a channel in between carbonate coral reefs. The Littlemore Shell Bed, laid down during a period of intense sediment starvation, contains a stratigraphically valuable ammonite fauna displaying Boreal as well as Tethyan affinities.

CROSS ROADS QUARRY (SP 550 064–SP 550 065)

J.K. Wright

Introduction

This quarry lies in the once heavily quarried Headington area of Oxford (Figure 2.47), and has played a prominent role in most accounts of Corallian stratigraphy since it was first described by Arkell (1927). The quarry is no longer in active use and is conserved as part of a public park by Oxford City Council, who have renamed it 'Rock Edge Quarry'. It presents a fine NNE–SSW-trending exposure some 100 m in length where lateral facies changes in carbonate rocks can be closely followed. Arkell's original description, his later papers (Arkell, 1936b, 1947b) and his book *Oxford Stone* (1947c), emphasize the stratigraphical and sedimentological value of the site. Cross Roads Quarry has subsequently figured briefly in the works of McKerrow and Baden Powell (1953), Wilson (1968a), McKerrow and Kennedy (1973) and Johnson (1983), and was well illustrated by Horton *et al.* (1995).

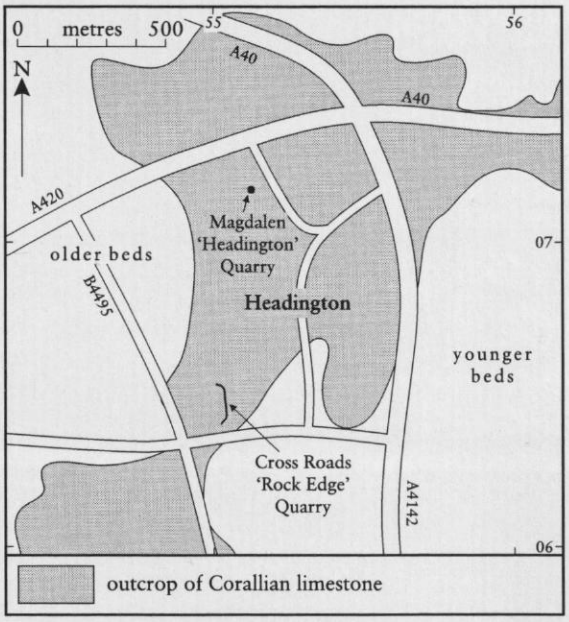

Figure 2.47 Locality map for Cross Roads Quarry and Magdalen Quarry. Outcrop of the Corallian limestones from BGS Sheet 237 (Thame) (1994).

Description

Three major stratigraphical units have been recognized in the 7 m succession of Corallian rocks recorded at this site. Present exposure does not permit all of Arkell's (1927) observations to be verified as the basal unit in the quarry, the Beckley Sand Member, is not currently exposed. The following section was measured by the present author at the southern end of the quarry. Details of the Beckley Sand Member are taken from Arkell (1927):

	Thickness (m)
Stanford Formation	
Wheatley Limestone Member	
4. Massive, rubbly-weathering, bioclastic limestone, a coral–shell sand with coral clasts up to 5 mm diameter, and occasional transported masses of *Thamnasteria concinna* (Goldfuss) bored by *Lithophaga inclusa* (Phillips)	seen to 1.0
3. Rubbly-weathering, bioclastic limestone packed with coral clasts, up to 10 mm diameter in the lower part, becoming finer grained upwards	seen to 2.3
(not exposed – ?Wheatley Limestone – 2.2 m)	
Kingston Formation	
Beckley Sand Member	
(2. *Headington Shell Bed*	0.3)
(1. Soft sand	seen to 1.2)

Though there was at one time a substantial exposure here of the Headington Shell Bed, Arkell (1927) does not refer to it, and it is unlikely the bed was visible in Arkell's day. However, it is very likely that many of the ammonites in museums located simply as 'Headington' came from this quarry. The following ammonites are listed by Arkell (1935–1948) as occurring in the shell bed at Headington (i.e. not specifically at

Vicarage or Magdalen quarries, these being listed below; see site report for Magdalen Quarry, this volume):

Perisphinctes (Dichotomosphinctes) rotoides Ronchadzé, *P. (Arisphinctes) maximus* (Young and Bird), *P. (A.) cotovui* Simionescu, *P. (A.) pickeringius* (Young and Bird), *Cardioceras (Cuneicardioceras) cuneiforme* Arkell, *C. (Subvertebriceras) densiplicatum* Boden, *C. (S.) zenaidae* Ilovaisky, *C. (Vertebriceras) dieneri* Neumann and *Goliathiceras titan* Arkell.

Rubbly, thick-bedded Wheatley Limestone containing large coral clasts occurs at the southern end of the quarry. In the central and northern sectors of the face, thinly bedded limestone with smaller coral clasts predominates (Figure 2.48). The fauna of the Wheatley Limestone is dominated by corals. Clasts and larger masses of the colonial reef coral *Thamnasteria concinna* are profusely abundant, and some layers are crowded with fragments of the branching coral *Thecosmilia annularis* (Fleming). Amongst the bivalves, *Nanogyra nana* (J. Sowerby) is extremely abundant, along with fragments of *Trichites* and *Chlamys*, and there is a variety of echinoid spines, including *Paracidaris florigemma* (Philips) and numerous smaller spines. This fauna occurs variously rolled, bored and abraded. It is clear that a rich and diverse assemblage of invertebrate taxa, dominated by corals, echinoids and bivalves, can be collected here.

Interpretation

The *Vertebriceras* and *Goliathiceras* recorded here from the Headington Shell Bed are indicators of the Vertebrale Subzone. The perisphinctids could indicate either Vertebrale Subzone or Antecedens Subzone (the latter approximately equivalent to the Maltonense Subzone). Evidence from Magdalen Quarry (see below) suggests that the Maltonense Subzone is present at Cross Roads Quarry, and it is likely that the Headington Shell Bed here encompasses in its 0.3 m both Vertebrale and Maltonense Subzones (Callomon, 1960).

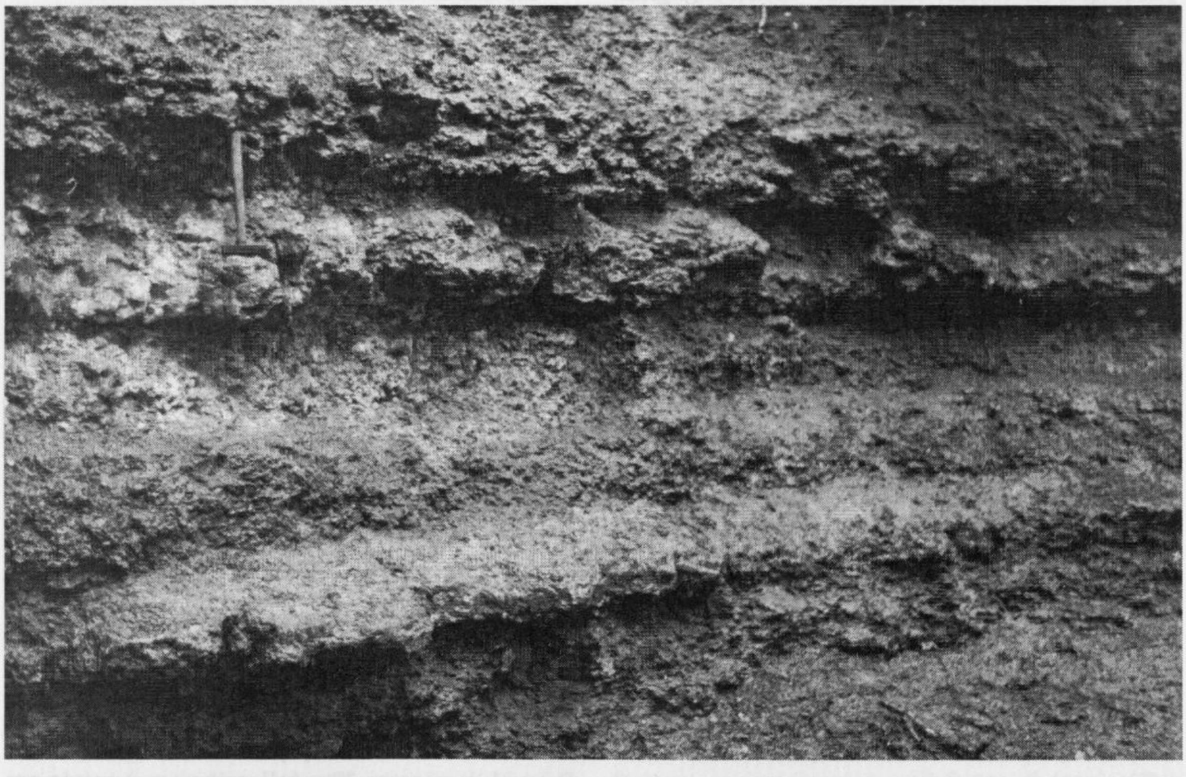

Figure 2.48 View of the central face at Cross Roads (Rock Edge) Quarry, showing the regular bedding in coralliferous calcarenite of the Wheatley Limestone. The coral clasts rarely exceed 10 mm in diameter. Hammer shaft is 30 cm long. (Photo: J.K. Wright.)

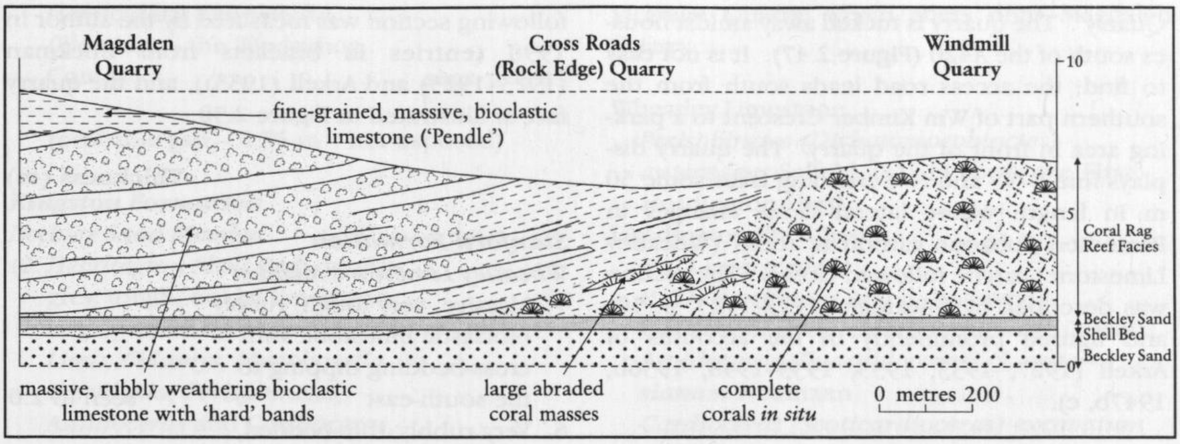

Figure 2.49 Correlation of sections in Magdalen Quarry, Cross Roads Quarry and Windmill Quarry (after Arkell, 1927, fig. 11), showing the transition from Coral Rag reef facies on the right into Wheatley Limestone facies on the left.

The Wheatley Limestone is present here in its coarse-grained coralliferous facies proximal to coral reefs. True Coral Rag with large coral masses was exposed only 500 m to the south at Windmill Quarry (Figure 2.49). The term Wheatley Limestone is used here in preference to Coral Rag for the coralliferous beds at the southern end of Cross Roads Quarry. This is because the massive corals present are transported and preserved in coarse-grained, bioclastic sand, rather than in the fine, micritic limestone laid down within the coral reef complexes. Wilson (1968a) described the reef margin facies here as a coralliferous rock composed of solitary or massive crystalline colonies of *Thecosmilia, Isastraea* and *Thamnasteria*. The coarse-grained nature of the coral clasts indicates the proximity of the true reef.

Away from the reef margin, in the central and northern parts of the section (Figure 2.49), finer-grained detrital carbonate facies interdigitates with rubbly coral conglomerate, possibly laid down during storms. Fragments of *Thamnasteria* up to 20 mm in diameter are found in a lens of coral–shell conglomerate occurring about the middle of the length of the quarry face. The Wheatley Limestone here is thus seen both in its rubbly coral debris facies (Wilson, 1968a, Facies 3), and in its shelly, bioclastic facies (Wilson, 1968a, Facies 4). Within the area of the Oxford reef, which was situated to the south and west of the present site, debris biosparites are distributed between the larger coral masses, suggesting penecontemporaneous abrasion of well-indurated reef-rock in a relatively high-energy depositional environment.

Insalaco (1996) noted that the growth rate of corals in the Oxford reef, as measured by annual growth bands, was much less that that of corals of equivalent age in France. He attributed this to the adverse effects of a larger amount of run-off affecting the Oxford reef from the nearby London Landmass.

Conclusions

This is a key site in palaeogeographical reconstructions and facies analysis of the Oxfordshire coral reefs of late Jurassic (Oxfordian) age. The complete transition from broken marginal reef to comparatively fine-grained coral–shell sand may be observed here.

MAGDALEN QUARRY (SP 552 072)

J.K. Wright

Introduction

Magdalen Quarry (or 'Workhouse Quarry') has its earliest known reference in 1610 (Arkell, 1947c, p. 49). The quarry was worked for building stone until just before World War I (Pringle, 1926). Since then it had deteriorated, but has recently been cleaned up and fenced off, and is now managed as a nature reserve by Oxford City Council, who have renamed it 'Headington

Quarry'. The quarry is tucked away amidst houses south of the A420 (Figure 2.47). It is not easy to find; the access road leads south from the southern part of Wm Kimber Crescent to a parking area in front of the quarry. The quarry displays fine E–W- and N–S-trending faces some 50 m in length where lateral facies changes in Parandieri Subzone carbonate rocks (Wheatley Limestone) can be followed closely. The section was described by Buckman (1923–1925, p. 50) and figured prominently in the accounts of Arkell (1927, 1933, 1935, 1933–1948, 1936b, 1947b, c).

Description

When first described by Buckman (1923–1925), the quarry showed a 6 m sequence of Corallian rocks. A drawing of the quarry face as seen in the 1920s was figured by Arkell (1927, 1933). However, exposure at the time of writing does not permit all the observations of the early workers to be verified as the lowest 1–2 m are shallowly buried beneath a cover of loose talus. The following section was measured by the author in 1998 (entries in brackets from Buckman (1923–1925) and Arkell (1933)), and the quarry face is illustrated in Figure 2.50.

	Thickness (m)
Stanford Formation	
Wheatley Limestone Member	
7. Massive, very tough, rubbly bioclastic limestone with cross-bedding dipping to the south-east	seen to 2.0
6. Very rubbly, thin-bedded, micritic or clayey, shelly limestone	0.50
5. Medium-grained, bioclastic limestone (the 'First Headington Hard')	0.35
4. Rubbly, poorly bedded, bioclastic limestone	0.45
3. Tough, medium-grained bioclastic limestone containing numerous spines of	

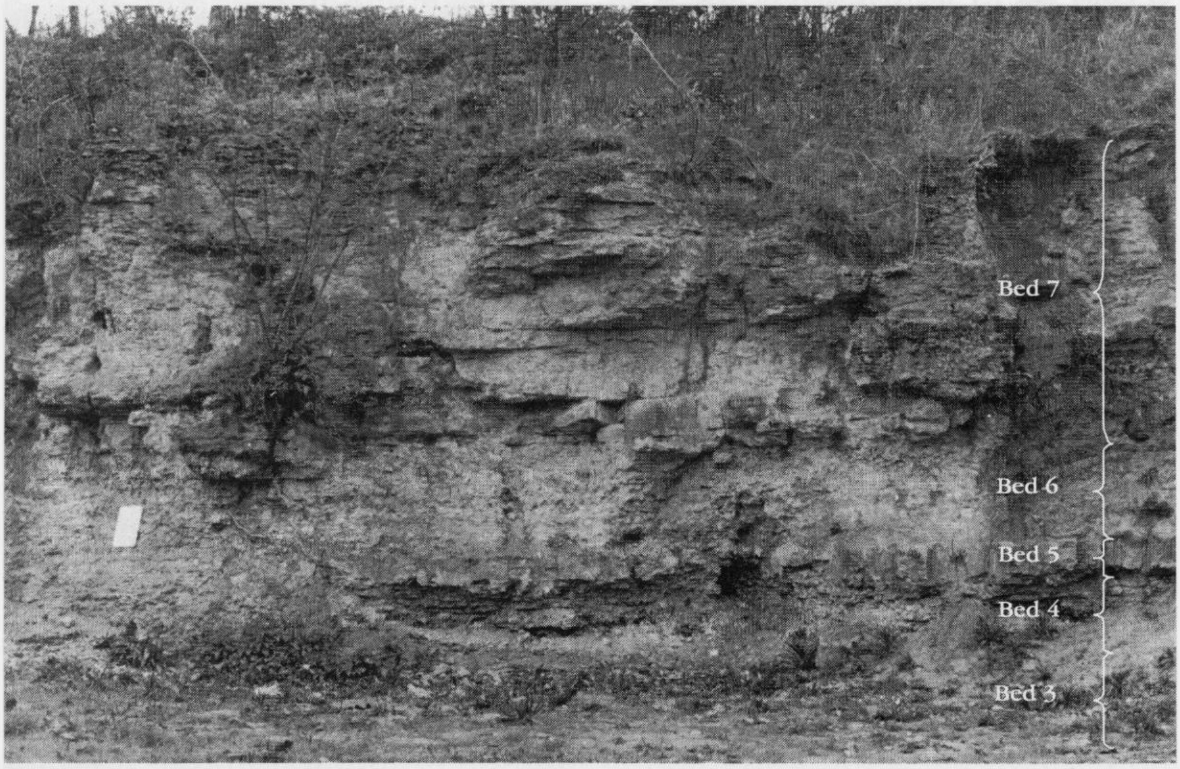

Figure 2.50 View of the main east–west face at Magdalen Quarry showing the irregularly bedded Wheatley Limestone. The 'First Headington Hard' (Bed 5, 0.35 m) is just below the level of the mapcase (36 cm long). (Photo: J.K. Wright.)

Hemicidaris intermedia (Fleming) – the 'Hedgehog Course' seen to 0.45

(probable gap – 0.75 m – not exposed)

Kingston Formation

Beckley Sand Member

(2. *Headington Shell Bed*: bluish-grey, tough, ooidal limestone, largely made up of fossils, with *Lima, Chlamys, Myophorella, Gervillella, Perisphinctes, Aspidoceras* and *Cardioceras*, etc.. Numerous 'lydite' and grey limestone pebbles present, with pyrite and carbonaceous matter 0.3)

(1. Soft sand seen to 0.9)

The Beckley Sands (Bed 1) were described by Buckman (1923–1925) as soft sands without hard bands or doggers.

Bed 2, the Headington Shell Bed, contains a remarkably prolific fauna of bivalves and ammonites exceptionally well preserved in its fine micritic matrix.

Beds 3–7 (Wheatley Limestone) contain numerous well-rounded coral clasts mostly 2–2.5 mm in diameter. Most bivalves are comminuted, with occasional *Nanogyra nana* (J. Sowerby). The rock weathers very readily, but the two beds of bioclastic limestone, beds 3 and 5, stand out. As was noted by Arkell (1933), there is substantial facies variation within Bed 7 in the quarry. The specific layers of hard limestone (the Second and Third Headington Hards) are difficult to make out now, but the general pattern is still recognizable. In the north-west end of the quarry the rock is tougher and coarser (Arkell's 'Nodular Rubble'), with abundant coral clasts between 5 and 10 mm in diameter. *Fungiastraea arachnoides* (Parkinson), *Thamnasteria concinna* (Goldfuss), *Thecosmilia annularis* (Fleming) and *Rhabdophyllia phillipsi* Edwards and Haime are all represented. Passing eastwards, the coral clasts become smaller, between 2 and 5 mm in diameter, and beds of fine- and medium-grained coral–shell sand alternate. At the south-east end of the quarry little bedding is seen, and Bed 7 has become a fine-grained, white, porous, massive, bioclastic limestone, the 'Pendle' of the quarrymen.

The following is a complete list of ammonites recorded from this quarry and from the nearby Vicarage Quarry, which abuts onto Magdalen Quarry:

Wheatley Limestone

Perisphinctes (Dichotomosphinctes) antecedens Salfeld, 0.45 m above the First Headington Hard.

Headington Shell Bed

P. (D.) antecedens

P. (D). buckmani Arkell (holotype)

P. (Perisphinctes) chloroolithicus (Gümbel)

Aspidoceras (Euaspidoceras) cf. *vettersianum* Neumann

Cardioceras (Scoticardioceras) excavatum (J. Sowerby)

C. (Subvertebriceras) costulosum (Buckman) (holotype)

C. (Sagitticeras) moderatum (Buckman) (holotype)

C. (S.) cariniferum (Buckman) (holotype)

Goliathiceras (Goliathiceras) ammonoides (Young and Bird)

G. microtrypa (Buckman) (holotype)

G. elegans Arkell

G. chamoussetiforme Arkell

Interpretation

In their respective monographs, both Buckman (1923–1925) and Arkell (1935–1948) emphasize the importance of the ammonite assemblages occurring here. The bulk of the specimens came from the Headington Shell Bed. The occurrence of so many species of *Goliathiceras* and *Sagitticeras* is a firm indication of the presence of the Vertebrale Subzone – yet the occurrence of the *Dichotomosphinctes* and *Perisphinctes* (*sensu stricto*) is an equally firm indicator of the presence of the Antecedens Subzone (approximately equivalent to the Maltonense Subzone). Because of this, Callomon (1960) was driven to the conclusion that both subzones are present in the 0.3 m thickness of the shell bed, the Vertebrale and Maltonense Subzones having joined together into a single homogeneous bed. The Headington Shell Bed thus represents a remanié deposit laid down during a period of intense sediment starvation over a considerable period of time. The shells are perfectly preserved, with little abrasion or fracturing during transport. The bivalves represent shallow-burrowing, surface-dwelling and free-swimming forms. Here and elsewhere around Oxford, the Wheatley Limestone yields a Sub-Boreal

Parandieri Subzone fauna, almost certainly equivalent in this case to the Boreal Tenuiserratum Subzone.

The Wheatley Limestone as developed at this site represents an opportunity to examine a facies intermediate between the wholly detrital carbonate accumulations of the Wheatley district and the true coral bioherms formerly visible only 1.2 km south at Windmill Quarry (Figure 2.49). The size of the coral clasts at the north-west end of Magdalen Quarry shows that the sediment was accumulating very close to a coral reef, as at the Cross Roads site, but no sign of in-situ corals is seen. The Wheatley Limestones of Magdalen Quarry may be regarded as forming a reef-flank facies, dipping off the eastern side of the Oxford reef development (Figure 2.49). In only a short distance the transition from coarse reef rubble to finer grainstones may be observed. Arkell's drawing of the quarry face (1927, 1933), made when the face was better exposed than it is at the time of writing, shows all horizons within the quarry section thinning to the east, particularly the Nodular Rubble and the 'Hard Bands' and 'Hedgehog Course' (whose 'hedgehog' spines were, of course, echinoid spines). These thin, tough limestones were the beds sought by the quarrymen for building stone, but, being porous, they are not particularly resistant to weathering, and are now regarded as an unfortunate choice for that purpose. The 'Pendle' is thickest in the eastern side of the quarry. It is a whiter and more comminuted detrital facies than occurs at Wheatley, 4 km to the east.

Conclusions

This site is essential to the palaeogeographical reconstruction of coral reef development in the vicinity of Oxford in late Jurassic (Mid Oxfordian) times. Rapid lateral lithological and thickness changes are well displayed within the Wheatley Limestone of the quarry section, and in a short distance a complete transition from coarse reef rubble to finer grainstones may be observed. The Headington Shell Bed has been an important source of ammonites, with the very close juxtaposition of Vertebrale Subzone cardioceratids and the immediately overlying Maltonense Subzone perisphinctids, all within one 0.3 m bed. The ammonites are beautifully preserved, and the holotypes of five ammonite species have been collected from the Shell Bed at this quarry or at the adjacent Vicarage Quarry.

LYE HILL QUARRY (SP 592 068)

J.K. Wright

Introduction

Lye Hill Quarry provides the thickest, best-exposed and most accessible succession in the Parandieri Subzone Wheatley Limestone. The quarry is situated immediately north of the A40 at its junction with the B4027. It provides an extensive exposure, with its four faces varying between 50 m and 150 m in length. It was first referred to by its present name early in the 20th century (Davies, 1909) although several previous descriptions of exposures in the Wheatley Limestone in the vicinity (Hull and Whittaker, 1861; Blake and Hudleston, 1877; Woodward, 1895; Blake, 1902a) may include this site.

The exposure was mentioned by Pringle (1926), but it was the researches of Arkell in the Oxford district (see below) that gave Lye Hill Quarry its full prominence. Subsequently, the site has received further attention through the work of McKerrow and Baden Powell (1953) and Callomon (1960), and it later figured prominently in the major work of Wilson (1968b) on carbonate facies variations within the Osmington Oolite and Coral Rag. The succession was studied in detail by Horton *et al.* (1995), who produced a radically revised interpretation of the section. Though well conserved, Lye Hill Quarry is at the time of writing being used as a car storage area, and as such is not suitable for visits by parties.

Description

The quarry section lies entirely within the Wheatley Limestone Member of the Stanford Formation. The term 'Wheatley Limestone' was first employed by Blake and Hudleston (1877) to describe this detrital equivalent of the Coral Rag reef facies. In general terms, the Wheatley Limestone consists of massive-bedded, very rubbly weathering, medium- to coarse-grained biomicrites largely devoid of recognizable corals. Harder beds of densely bioclastic limestone with a partial sparry cement alternate with softer micritic beds.

The whole has a pronounced easterly dip, and this has given rise to a certain amount of controversy. Blake and Hudleston (1877), Arkell

(1942, 1947b) and Wilson (1968b) were convinced that the true dip in this area was almost horizontal, and that the dip of 8° to the east seen in the quarry was depositional, the shelly limestones dipping off the Oxford coral reef situated to the west (see report for Cross Roads Quarry).

Pocock *et al.* (1908) felt that it was not clear to what extent the bedding in the quarry was cross-bedding rather than true bedding. Horton *et al.* (1995) established by mapping that the regional dip in the Wheatley area is 8° to 10° to the east, and that the bedding seen in the quarry is therefore true bedding, not cross-bedding. The presence of large-scale cross-bedding could not be substantiated. The total thickness measured bed by bed is 26 m. Elsewhere, a maximum of 10 m of Wheatley Limestone is seen. Horton *et al.* agreed with Arkell (1947b) that the anomalous thickness of 26 m was due to the situation of the Lye Hill area within the Wheatley Fault Zone, and that fault movement during the Oxfordian led to a substantially increased thickness of Wheatley Limestone.

The section below is taken from Horton *et al.* (1995).

	Thickness (m)
Stanford Formation	
Wheatley Limestone Member	
26. Hard, flaggy limestone	0.4
25. Buff marl passing laterally into rubbly-weathering limestone	0.85
24. Hard, compact, medium- to coarse-grained oobioclastic limestone	0.57
23. Shelly, medium- to coarse-grained marl with abundant *Nanogyra nana* (J. Sowerby)	0.75
22. Generally well-cemented, massive, very pale fawn limestone with abundant medium to coarse shell debris	1.15
21. Shelly marl	0.08
20. Hard, medium-grained, bioclastic limestone with abundant *N. nana*, serpulids and rarer echinoids	2.30
19. Shelly marl	0.08
18. Massive bioclastic limestone	1.18
17. Shelly marl	0.08–0.12
16. Medium- to coarse-grained, rubbly limestone with differential cementation	1.55
15. Rubbly bioclastic limestone with pockets and lenses of marl and micritic limestone	0.75
14. Hard, massive, bioclastic limestone	0.38
13. Bioclastic limestone, massive below, nodular at the top, with marl and micrite lenses	0.53
12. Grey and brown banded marl passing laterally into limestone	0.45
11. Medium-grained bioclastic limestone with well-rounded shell debris	0.83
10. Shelly marl	0.02
9. Medium-grained bioclastic limestone with low-angle cross-stratification	0.72
8. Shelly marl	0.05
7. Thinly bedded bioclastic limestone with scattered shelly bands, mostly oyster	2.10
6. Shelly marl	0.03–0.07
5. Medium-grained bioclastic limestone with many *N. nana*	2.10
4. Shelly marl	0–0.02
3. Medium- to coarse-grained, banded, oobioclastic limestone with scattered *N. nana*	1.20
2. Shelly marl	0.04
1. Medium-grained bioclastic limestone with banding due to differential cementation	seen to 3.30
(Shell–Pebble Bed seen in the floor of the quarry in 1945 by H. J. Hambige; in Callomon, 1960, p. 197).	

A loose block, probably from Bed 15, contained *Nanogyra nana*, *Pseudomelania heddingtonensis* (J. Sowerby), echinoid fragments and fish teeth. These occurred along with pisoids, 1.5–2 mm diameter coral fragments and shell fragments in a grey, argillaceous, micritic matrix. Callomon (1960) lists the following from the Wheatley Limestone of this area: *Perisphinctes (Perisphinctes) parandieri* de Loriol, *P. (P.) chloroolithicus* (Gümbel), *P. (Dichotomosphinctes) buckmani* Arkell and *P. (D.) auriculatus* Arkell.

Interpretation

Horton *et al.* (1995, fig. 14) plotted the distribution of Wheatley Limestone, Coral Rag and Littlemore Clay facies in the area to the east of Oxford. They noted that an area of patch reef with coral masses and interdigitating debrisfilled channels similar to that occurring at Cumnor (see site report for Cumnor, this volume) extends to just east of the A4142 on the eastern side of Oxford (Figure 2.47), and then NNE towards Beckley. East of this line, there are no coral masses, just detrital Wheatley Limestone. Lye Hill Quarry is thus situated some 4 km east of the nearest patch reef.

The Lye Hill site provides an ideal opportunity to examine in detail the composition of the Wheatley Limestone. The allochems are derived largely by micritization of well-packed, skeletal shell debris swept from the reef facies of the Oxford area. Frequently present are amorphous lumps (pisoids), the centres of which are often composed of a mosaic of calcite (Wilson, 1968b) suggesting their formation by algal degradation. The grain size of these sediments decreases from Beckley, 5 km to the north-west, to Wheatley, and this is accompanied by a change in particle type from mainly coralline debris to intrasparites (Folk, 1959).

The lack of coral debris only 4 km from the reef is remarkable, particularly when it is considered that coral debris was traced 20 km east of the Hackness coral–sponge reef in Yorkshire by Wright (1992; see report for Hackness Head). It is likely that current action at Oxford was stronger, and coral fragments were completely abraded before the shell debris reached the Lye Hill area. These detrital carbonates forming the Wheatley Limestone were thus deposited on the margins of the deeper water east of the Oxford reef. Clay-rich limestones laid down under gentle offshore marine conditions alternate with highly comminuted, cross-bedded shell debris laid down during storms. The frequent occurrence of nests of *Nanogyra* cemented together suggests in-situ growth of small oyster patch reefs. These represent the only faunal elements able to tolerate the unstable substrate, the bivalves cementing to each other in the rapidly shifting depositional environment. Rapid subsidence within the Wheatley Fault Zone allowed the accumulation of reef detritus beds four times thicker than the reef itself (Arkell, 1927).

The extensive perisphinctid fauna of the Wheatley Limestone is the type fauna of the Parandieri Subzone of Callomon (1960). Correlation of this Sub-Boreal subzone with the standard Boreal zonal scheme is not certain, but the Parandieri Subzone is probably equivalent to the upper part of the Tenuiserratum Subzone and the Blakei Subzone (Wright, 1996a).

Conclusions

This is a key Corallian locality in any facies analysis of the Oxford coral-reef area. The site displays extensive sections in the Wheatley Limestone, of Mid-Oxfordian age, only a kilometre from its type locality. This site marks a strategic position in Middle Oxfordian palaeogeography, as increasingly argillaceous facies replace carbonates north-eastwards along the Corallian outcrop (Horton *et al.*, 1995). The facies characteristics of the Lye Hill sequence reflect this change in the nature of the depositional environment as the Wheatley Limestone grades laterally into the 5 m thick deposits of marl and clay termed the Oakley Beds in north Oxfordshire, Buckinghamshire and Bedfordshire.

LITTLEWORTH BRICK PIT (SP 588 054)

B.M. Cox

Introduction

Littleworth Brick Pit (sometimes known as 'Wheatley Brick Pit') at Wheatley, *c.* 3 km east of Oxford, is at the time of writing occupied by a mobile home park, and the section for which it has long been famous is presently obscured. It formerly exposed a small thickness of Lower Kimmeridge Clay overlain by Upper Kimmeridge Clay and then limestones and sandstones of Portlandian and Early Cretaceous age. A peculiarity of the Upper Kimmeridge Clay in this region is the widespread development within it of units of sand and silt (see also site report for Old Town, Swindon, this volume). The sequence was extensively worked for brick-making as the sands and silts helped to prevent the clays from shrinkage, and the beds could also be dug in conjunction with sand and limestone from the overlying Portland Formation. Littleworth Brick Pit was the last surviving working pit, showing a fuller section of the Kimmeridge Clay than any other exposure in the area (Arkell, 1947b). Wheatley gives its name to the Wheatley Sand, in the top part of the Upper Kimmeridge Clay of the area, and to the Wheatley Nodule Bed, a bed of cementstone nodules yielding well-preserved 'pectinatitid' ammonites described and figured by Neaverson (1925). These include ***Pectinatites (Virgatosphinctoides) wheatleyensis*** (Neaverson) (Figure 2.51)

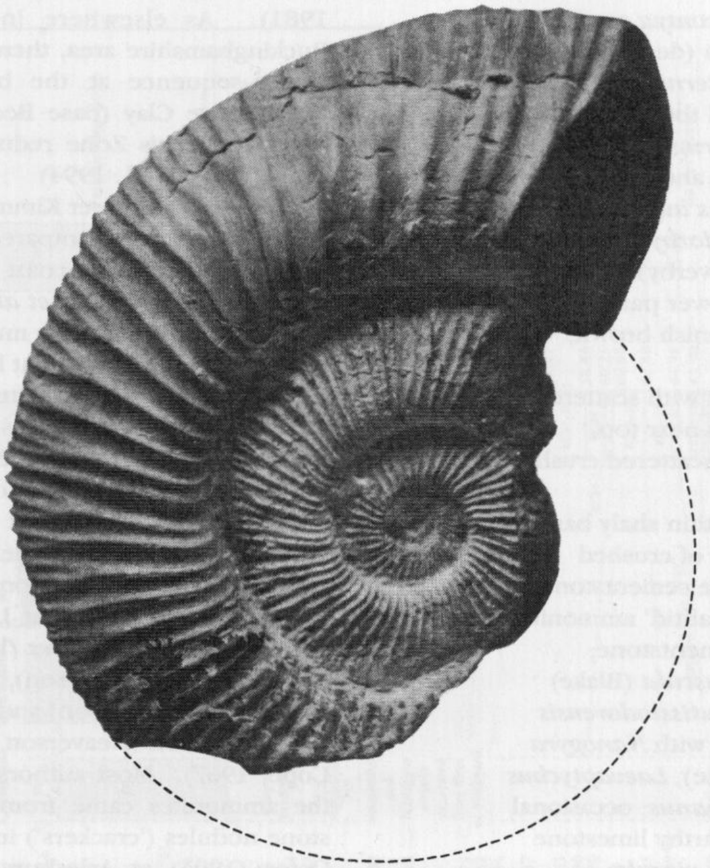

Figure 2.51 The type specimen of *Pectinatites (Virgatosphinctoides) wheatleyensis* (Neaverson) as figured by Neaverson (1925, pl.1, fig. 1). Natural size.

which gives its name to the Upper Kimmeridgian Wheatleyensis Zone (Cope, 1967).

Description

The following description of the Kimmeridgian strata is based on earlier accounts by Pringle (1926), Arkell (1933, 1942, 1947b), McKerrow and Kennedy (1973), and Horton *et al.* (1995). Bed numbers are those of Pringle (1926); after the time of Pringle's description, the brick pit was extended into the hill and joined up with the sand pit below the windmill (Arkell, 1942). The stratigraphical classification follows Horton *et al.* (1995).

Thickness (m)

Kimmeridge Clay Formation

Wheatley Sand Member

Sand, sharp, buff to grey; very poorly fossiliferous; small-scale sedimentary structures — up to 3.7

Swindon Clay Member

8. Clay, grey; small brown nodules containing fragments of *Pavlovia*; other fossils including *Modiolus* and *Thracia* — 3.0–3.7

Pectinatus Sand Member

7. Sandstone, brown, soft, friable, discontinuous; crowded with fossils including many large 'pectinatitid' ammonites, bivalves including *'Astarte' saemanni* de Loriol, *Camptonectes auritus* (Schlotheim), *Entolium nitescens* (Phillips), *Hartwellia bartwellensis* (J. de C. Sowerby), *H. swindonensis* (Blake), *Liostrea expansa* (J. Sowerby), *'Lucina' substriata* Roemer, *Mactromya verioti* (Buvignier), *Myoconcha saemanni* Dollfus, *Myophorella swindonensis* (Blake), *'Perna' listeri*

(Fleming), *Pleuromya* sp., *Protocardia morinica* (de Loriol) and *Pseudolimea alternicosta* (Buvignier), and the gastropod *Bathrotomaria rugata* (Benett)	1.2
6. Clay, sandy, lilac and greenish brown; *Musculus autissiodorensis* (Cotteau), *Pseudorhytidopilus latissima* (J. Sowerby) and *Dicroloma* in lower part	1.7
5. Clay, sandy, greenish brown, unfossiliferous	0.4
4. Clay, sandy, dark with scattered isolated nodules near top	1.4
3. Clay, dark grey; scattered crushed ammonites	1.1
2. Clay, dark grey; thin shaly bands and many layers of crushed ammonites; large cementstone nodules; 'pectinatitid' ammonites preserved in cementstone; *Isocyprina minuscula* (Blake) and *Musculus autissiodorensis*	2.7
1. Clay, dark, shaly with *Nanogyra virgula* (Defrance), *Laevaptychus* and *Aulacostephanus*; occasional hard lumps of earthy limestone crowded with *N. virgula*; *Aspidoceras* near base	seen to 2.4

The Wheatley Sand is overlain by the Upper Lydite Bed, a thin (0.03 m) seam of greenish grey, clayey, highly glauconitic silt with scattered lydite pebbles. This marks the unconformity at the base of the Portlandian succession, the lower part of which here comprises greenish-grey, sandy, glauconitic limestone and calcareous sandstone with scattered shell debris and abundant bivalves and ammonites (Horton *et al.*, 1995).

Interpretation

The lowest strata exposed belong to the Lower Kimmeridgian Eudoxus Zone. Evidence from Bed 1 suggests the presence of two well-established marker horizons of that zone. Pringle's (1926) record of 'hard lumps of earthy limestone crowded with the shells of *Exogyra* [*Nanogyra*] *virgula*' indicates the Virgula Limestone, and specimens in the BGS collections of *Aspidoceras* in solid preservation suggest the Crussoliceras Band (= the *Propectinatites*-rich band of Cox and Gallois, 1981). As elsewhere in the Oxfordshire–Buckinghamshire area, there is almost certainly a non-sequence at the base of the Upper Kimmeridge Clay (base Bed 2) here, with the Autissiodorensis Zone reduced or absent altogether (Cox *et al.*, 1994).

Although the Upper Kimmeridgian succession is attenuated here compared with the type sections on the Dorset coast (*c.* 16 m compared with over 270 m) (Cox *et al.*, 1991), it includes ammonite faunas that are much better preserved than those from equivalent levels in Dorset and, in the past, they have attracted considerably more attention. For instance, Neaverson's (1925) zonal scheme for the Upper Kimmeridge Clay was largely based on ammonite data obtained from the Oxford area (Cope, 1967). Cementstone nodules yielded the well-preserved 'pectinatitid' ammonites of the Wheatley Nodule Bed including, at Littleworth, the type specimens of *Pectinatites (Virgatosphinctoides) wheatleyensis* (Neaverson), *P. (V.) wheatleyensis delicatulus* (Neaverson) and *Sphinctoceras crassum* Neaverson (Neaverson, 1925; Arkell, 1933; Cope, 1967). Most authors have assumed that the ammonites came from the large cementstone nodules ('crackers') in Bed 2 but work by Oates (1991) at Aylesbury showed that they came from smaller, less conspicuous septarian nodules a little higher in the succession, albeit still within Pringle's Bed 2. The large 'crackers' occur in all sections that have yielded the typical ammonite fauna of the Wheatley Nodule Bed, possibly as far west as Chawley, 5 km west of Oxford (Horton *et al.*, 1995). The detailed classification and correlation of this lower part of the Upper Kimmeridge Clay remains somewhat problematic in this area because the succession is much thinner and less complete than both the type succession on the Dorset coast (see above) and that in eastern England, which is well known from boreholes. It contains many minor non-sequences marked by burrowed horizons and phosphatization; ammonites are commonly infilled with cream- or buff-coloured phosphate (Cox *et al.*, 1994). Although the ammonite fauna of the Wheatley Nodule Bed has long been considered to be a classic assemblage of the Wheatleyensis Zone, data from other local sections (Figure 2.52) suggest that the bed lies within KC44 of the standard bed-numbered Kimmeridge Clay sequence and therefore in the Hudlestoni Zone. More work is needed to resolve this apparent paradox (Cox *et al.*, 1994).

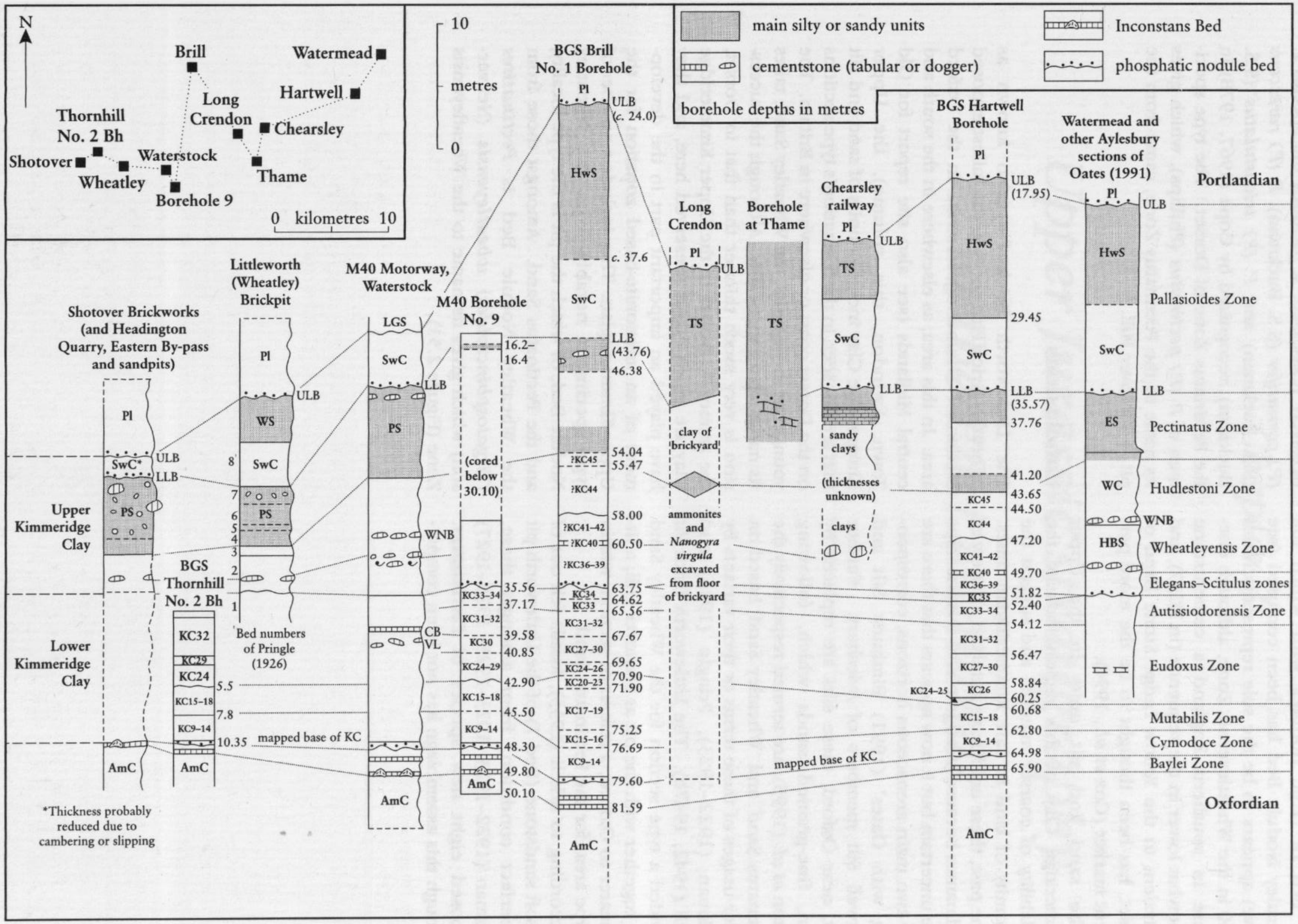

Figure 2.52 Graphic sections showing the Kimmeridgian stratigraphy at the Littleworth Brick Pit and other sections in Oxfordshire and Buckinghamshire, after Horton *et al.* (1995, fig. 17). AmC, Ampthill Clay; CB, Crussoliceras Band; ES, Elmhurst Silt; HBS, Holman's Bridge Shale; HwS, Hartwell Silt; KC, Kimmeridge Clay; LGS, Lower Greensand; LLB, Lower Lydite Bed; Pl, Portland Formation; PS, Pectinatus Sand; SwC, Swindon Clay; TS, Thame Sand; ULB, Upper Lydite Bed; WC, Watermead Clay; WNB, Wheatley Nodule Bed; WS, Wheatley Sand; VL, Virgula Limestone.

The bed of large nodules with which the Wheatley Nodule Bed has been confused (see above) appears to be the sole representative of KC40 in the Wheatleyensis Zone, although elsewhere in southern England a cementstone somewhat lower in the sequence (in KC37), and equivalent to the Yellow Ledge Stone Band of Dorset, has been thought to be the more persistent marker (Cox *et al.*, 1994).

The sand and silt units in the Upper Kimmeridge Clay of this region indicate the availability of coarser material and suggest the proximity of land in Late Kimmeridgian times. In the past, these units have attracted a variety of local names because stratigraphical relationships were uncertain but it now appears that there are only two main arenaceous horizons, corresponding with Oates' (1991) Elmhurst Silt and Hartwell Silt members of Aylesbury. Further west, near Oxford, these silts are replaced by clean, fine-grained sands which, following Horton *et al.* (1995), are termed respectively the 'Pectinatus Sand' and 'Wheatley Sand' based on earlier usages of these terms or their variants by Buckman (1922–1923), Pringle (1926) and Arkell (1942, 1947b). The Littleworth Brick Pit provided a type section for the Wheatley Sand and, together with the pit at Shotover Hill, a little nearer to Oxford, a reference section, within its type area, for the Pectinatus Sand.

According to Arkell (1933), fossils fell out of the soft sandstone (Bed 7) of the Littleworth pit in perfect condition; from amongst these, Buckman (1922–1923, 1923–1925, 1925–1927) proposed eight new species of *Pectinatites*. Although this assemblage has not been comprehensively reassessed, it includes the species *P. (P.) cornutifer* (S.S. Buckman), *P. (P.) rarescens* (S.S. Buckman) and *P. (P.) tricostulatus* (S.S. Buckman), recognized by Cope (1967, 1978) in the Pectinatus Zone of Dorset. The type specimen of *P. (P.) pectinatus* (Phillips), which gives its name to the Pectinatus Zone, came from the pit at Shotover Hill.

Conclusions

The Littleworth Brick Pit (also known as 'Wheatley Brick Pit') showed the fullest exposed section of Kimmeridgian strata in the Oxford area. In this area, as elsewhere in the south and central Midlands (see also site report for Old Town, Swindon, this volume), the Upper Kimmeridge Clay includes units of sand and silt that are not seen in the formation's type sections on the Dorset coast or elsewhere in Britain. The younger of these units, the Wheatley Sand, takes its name from the locality. Although the succession is very much thinner than that in Dorset, the ammonite faunas of the Upper Kimmeridge Clay are much better preserved here, and they have played an important part in the development of an ammonite-based zonation for the Upper Kimmeridgian. They include a number of type specimens notably from the Wheatley Nodule Bed, of which the pit is the type locality, and the Pectinatus Sand. Amongst those from the Wheatley Nodule Bed is *Pectinatites (Virgatosphinctoides) wheatleyensis* (Neaverson) which gives its name to the Wheatleyensis Zone (Figure 2.51).